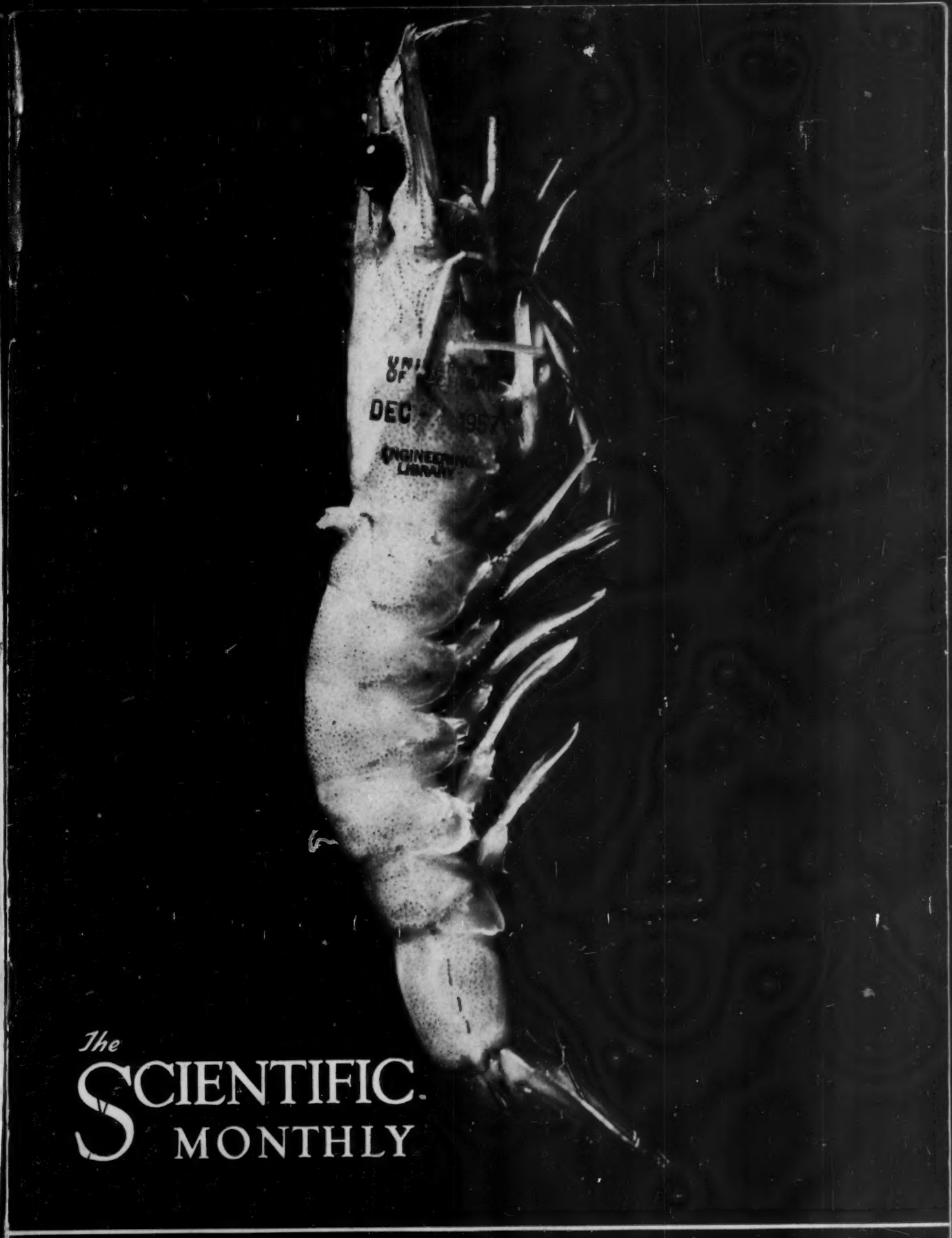
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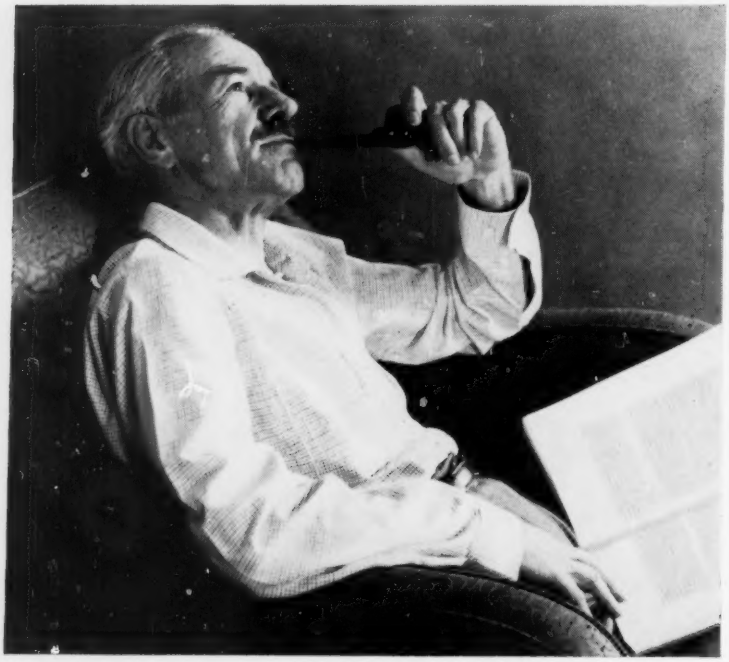

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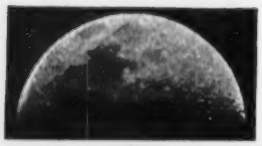

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Outlook to Space Travel

ERNST STUHLINGER

Dr. Stuhlinger was born in 1913 in Niederrimbach, Germany. He attended the University of Tübingen and received his doctorate in physics in 1936 for a thesis on "The ionization rate of cosmic rays." For almost 7 years he was a close associate of Hans Geiger, who developed the Geiger counter. In 1943, Dr. Stuhlinger joined the German Guided Missile Development Group at Peenemünde, where the V-2 missile was developed. Shortly after World War II he accepted a contract with the U.S. Department of the Army. Since early 1946 he has been working in this country on the development of guided missiles. At the present time he is director of the research projects office in the Army Ballistic Missile Agency, Huntsville, Ala. This article is based on an address given in the International Science Foundation's lecture series on International Cooperation in Science and Engineering, 24 October 1956, at the U.S. Naval Postgraduate School, Monterey, Calif.

WE usually understand history as a sequence of political events. However, the impact of technical achievements on our lives, at least when it is seen against a scale which counts in centuries, is often much more obvious than the precipitations of political successes and failures.

We choose for the beginning of the history of mankind the time when man learned to use fire; we speak of the Stone Age, the Bronze Age, and the Iron Age. The discovery of electricity and the invention of electric machines have probably changed our ways of life more than all the revolutions during the last 200 years. We may safely expect that later generations, when looking back to our present times, will not speak of the century of the world wars, but of the century in which man learned to leave the earth and reach out into the endless space which lies beyond.

Three brilliant men, almost at the same time some 30 years ago, recognized that travel through outer space is a real possibility with rocket-powered vehicles: Goddard, an American; Ziolkovsky, a Russian; and Oberth, a German. But only when the first large rocket-driven guided missiles were developed did we gain enough detailed technical knowledge and experience to make realistic design studies of space vehicles. During the last few years, numerous articles and books on space travel have been published. By far the most realistic studies were made by Wernher von Braun, the developer of the V-2 rocket.

A ship suitable for a round trip to Mars would have about 1700 tons initial weight, with 35 tons of pay load. The propellants are nitric acid and hydrazine. Several ships of a similar design, each carrying a crew of 6 to 8 men, would make the expedition. The travel time to Mars would be 260 days. The total time of the Mars expedition, however, includes a waiting period on Mars. This period is determined by the fact that the return trip must be accurately timed in order that the ship may meet the earth at a predetermined point on its ellipse around the sun. All told, the expedition would require a little more than 2.5 years.

The remarkable fact about von Braun's very de-

tailed Mars project is that it is based entirely on the technical and scientific knowledge which we have today. Speculations concerning future discoveries are strictly avoided.

Phases of the Voyage

It would be hopeless to try to design a space ship that would take off from the surface of the earth, overcome the atmospheric drag and the earth's gravity, cover the long distance between the earth and Mars, make a safe and gentle landing on the uninhabited planet, and still be prepared and equipped to make the return trip to its home base. Fortunately, this complex transportation problem can be handled by subdividing the voyage into several phases. Thus, the first step to interplanetary travel will be the establishment of a space station, orbiting around the earth as a satellite at an altitude of about 1000 miles above the surface. Commuter traffic from the earth to this space satellite will be made with large, three-stage rockets. The winged nose section of these rockets, a sort of fourth stage, will be used for the return trip from the satellite to earth.

The second part of an interplanetary trip covers the long stretch from the satellite station to an orbit around Mars. The space ship, traveling from the earth satellite toward Mars, will not land on Mars but will end its voyage in a circular orbit about 600 miles above the surface of the planet.

For the third phase of the trip, a winged landing craft will be detached from the orbiting ship. It will reduce its orbiting speed by rocket power and will enter a downward trajectory. After a long glide through the Martian atmosphere, it will land either on skids, like a glider, or by parachute and counterrockets.

At the end of the exploration period on Mars, the landing boat will take off from the planet by rocket power and return to the space ship, which will still be orbiting about the planet at an altitude of 600 miles. The crew will transfer back to the space ship and will make the return trip to the earth satellite. The final hop, from the satellite to the earth, will be made by means of the winged fourth "stage" of one of the commuter rockets.

The longest part of the voyage will be that between the satellite orbit around the earth and the orbit around Mars. The space ship will be tailor-made for the conditions that will prevail during this voyage. Quarters for the crew will be sealed and provided with an artificial atmosphere. The ship will not be streamlined, since it will travel only through perfect vacuum. The thrust of the rocket motors need not lift the vehicle against the forces of gravity, because these forces are exactly balanced by centrifugal forces in any object that moves around in a satellite orbit. Even a relatively low thrust will enable the ship to leave its original satellite orbit and to enter into a trajectory which finally approaches the Martian ellipse.

Construction Requirements

The space ship will be assembled in the satellite orbit close to the space station. All components of the ship, its equipment, and the fuel needed for the round trip must be carried into the satellite orbit by the three-stage commuter rockets. These carrier rockets must overcome the earth's gravity and atmospheric drag, and they must impart to their pay loads the orbital velocity of about 7 miles per second. This earth-orbit operation will be the most costly part of the entire Mars expedition. For every pound of pay load, about 160 pounds of take-off weight must be invested in the commuter rockets. The designer of the space ship will therefore make the greatest effort to keep his vehicle as light as possible. Furthermore, he will plan the expedition in such a way that any components which become unnecessary during the voyage, such as empty tanks, containers, supports, and even instrumentation, can be disposed of immediately. Ship and crew would finally arrive back in the earth-satellite orbit with a bare minimum of equipment and reserves.

By far the largest part of the take-off weight of such a space ship will be made up of the propellants. The attempt to reduce the mass of a space ship, therefore, leads immediately to an investigation of its propulsion system. The basic rocket equations show that the performance of a rocket engine is mainly determined by the exhaust velocity of the gases from the combustion chamber. Moreover, in rocket engines that are based on a chemical reaction between the propellants, the exhaust velocity is intimately related to the temperature inside the combustion chamber. The temperatures at which modern combustion chambers operate are close to the maximum temperatures which can be expected from chemical reactions. There is little reason to hope that the performance of chemical rocket motors can be improved much beyond the point at which we have arrived today.

Electric Propulsion Systems

It seems, however, that another type of reaction motor holds some promise for use in an interplanetary vehicle. If the velocity of the exhaust particles is produced, not by the heat energy of a chemical reaction, but by electric fields, much higher ex-

haust velocities can be obtained. The amount of electric energy which can be imparted to a given mass of exhaust material is much greater than the energy which can be given to the same mass by a chemical reaction. In addition, the electric field would direct the exhaust particles in such a way that they would not strike the walls of the thrust chamber. Hence, the wall-heating problem in an electric engine would be considerably less difficult than it would be in a chemical engine.

An electric propulsion system would require the ionization of a suitable propellant material. It would also require a primary power source, the conversion of the primary power into electric power, and a thrust chamber in which the electric power is applied to accelerate the ions.

A detailed study of the feasibility of an electric propulsion system has already been made. This study has proved that an electric system is feasible and that an electrically propelled space ship would be much lighter than a ship with a chemical propulsion system. The electric system would, however, be definitely restricted to space vehicles traveling between satellite orbits, because the thrust of an electric propulsion system would always be so small that it could never lift the vehicle from the surface of a planet against the gravity forces. The propulsion system would operate continuously, first accelerating the ship and later decelerating it by reversal of the thrust direction. In the Mars trip, for instance, the ship's velocity would increase steadily up to the point of thrust reversal and would then decrease to a point where, upon the approach to Mars, the ship would be captured by the planet's gravitational field. The primary power source must generate power throughout the time the ship is traveling. The total length of travel time for a round trip to Mars will be about 2 years.

Electric Space Ship

The basic assumptions that underlie the design of the electric space ship are a pay load of 150 tons and an acceleration of at least 6×10^{-5}g. The pay load includes the crew, with equipment and supplies of oxygen, water, and food; living quarters; observation instruments; and the landing craft, with equipment for the crew to subsist on Mars. The minimum acceleration must be great enough to make it possible to complete the round trip in a reasonable period of time and to allow for the expected corrective maneuvers during flight. A nuclear reactor is chosen as a primary power source. For weight-saving reasons, it is a "fast" reactor containing about 12 tons of uranium. Its uranium-235 content is enriched to about 1.7 percent. The reactor heat is absorbed by a cooling system that employs sodium-potassium as a coolant.

The reactor is located at a point about 250 feet away from the living quarters. It is shielded by a thick layer of beryllium and a sheet of boron, in order that the strong neutron and gamma radiations may be kept away from the living quarters. The heat energy that is contained in the sodium-potassium coolant is transferred to a working fluid (silicon oil) in the heat exchanger. Steam, produced in the heat exchanger, drives a turbine which is coupled to an electric generator. The steam which leaves the turbine enters a large radiation cooler, where it condenses again. From there, the fluid is pumped back to the heat exchanger.

The material best suited for the propellant is one that can be ionized easily and has a high ionization yield. An alkaline metal such as rubidium or cesium will be chosen. The atoms of these metals are ionized with almost 100-percent efficiency when they strike a hot surface of platinum foil. A temperature of about 200°C is enough to produce sufficient vapor pressure of the alkaline element. The vapor enters an ionization chamber that contains hot platinum grids, and the ions are extracted from the chamber by an electric field. This field accelerates the ions in the thrust chamber to a velocity of about 50 miles per second. They leave the propulsion system in a steady flow, representing an electric current. The electric power, which is determined by this current and by the potential difference through which the ions pass in the thrust chamber, must be provided by the electric generator.

The maximum current density which can be obtained in the thrust chamber is limited by space-charge effects. These effects also influence the formation of the jet of ions, which extends from the thrust chamber into empty space. An unlimited beam of ions—even a beam of a noticeable length—would be impossible. The space charge would act back on the thrust chamber and would neutralize the accelerating field.

In order to produce and maintain a continuous flow of particles out of the propulsion system, the ions must be electrically neutralized soon after they leave the thrust chamber. Fortunately, this neutralization can be achieved rather easily. When the alkaline atoms come in contact with the heated platinum grid, one negative electron jumps off of every atom, leaving a positive ion behind. The electrons enter into the platinum foil. These electrons must be expelled from the ship; otherwise, it would quickly assume a strong negative charge which would prevent any further expulsion of positive ions through the thrust chamber. The natural

way to neutralize the ions is to expel the electrons in the immediate vicinity of the ion thrust chambers. The two beams mix at a short distance behind the end of the thrust chambers, and the electrons join the ions to form a neutral plasma. In this way, the strong space charge of the exhaust jet is avoided.

An expulsion chamber for electrons consists of a hot filament which emits electrons, and a field of about 200 volts potential difference. One ion thrust chamber has a diameter of about 1 inch, and a total of many thousand thrust chambers will be needed to produce the thrust required for a space ship. The ion chambers and the electron chambers are tightly packed, so that neutralization of the charges occurs at a distance not greater than about 1 inch behind the thrust chambers. It is assumed that the power plant and thrust chambers will be in operation during the entire trip, either accelerating or decelerating the vehicle.

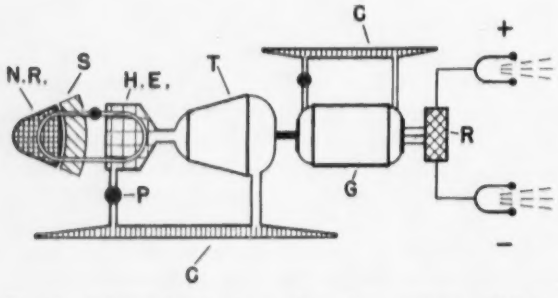

Fig. 1. Schematic diagram of nuclear reactor (N.R.), heat exchanger (H.E.), turbogenerator (T), pumps (P), coolers (C), rectifier (R), and ion and electron chambers (+ and −) in projected electric space ship.

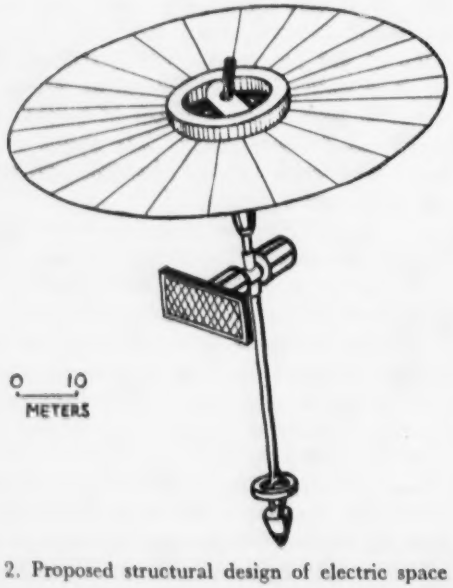

Fig. 2. Proposed structural design of electric space ship.

A schematic diagram of the nuclear reactor, the heat exchanger, the turbogenerator, and the ion and electron chambers is shown in Fig. 1. The largest component of the propulsion system will be the radiation cooler. The optimum size of the cooler is one for which the total mass of the power-generating system is a minimum, based on a given electric power output and a given temperature of the hot steam. The figure that characterizes the specific power of the power plant, measured as kilowatt output divided by total mass, proves to be one of the decisive figures from which the design of an electric space ship must start. This figure was found to be about 0.1 kilowatt per kilogram. From this figure, an assumed initial acceleration of 6.7×10^{-5} g, and a total pay load of 150 tons, the design data for a space ship capable of going to Mars and back can be derived.

The detailed study shows that for any given set of the four parameters, pay load, minimum acceleration, specific power, and destination, optimum values can be found for propellant mass, total power, and accelerating voltage. With these optimum values, the total initial mass of the space ship is a minimum. Values that differ from these optimum figures would result in a heavier ship.

The following design data were determined for the ship: total initial mass, 730 tons; propellant mass, 365 tons; total electric power, 23 megawatts; accelerating voltage, 4880 volts; exhaust velocity, 50 miles per second; total thrust, 110 pounds.

The travel time to Mars for this ship would be a little more than 1 year; the time for the trip back, a little less than 1 year. The ratio of total initial weight to pay load is less than 5 to 1—a very favorable figure for a rocket-propelled vehicle.

The structural design of the ship will take into account the absence of atmospheric drag and appreciable acceleration forces. Structural elements will be very light. The proposed design is shown in Fig. 2. The ship is symmetrical around the longitudinal axis, with the reactor at one end and the living quarters at the other. As soon as turbine and generator start to turn, the entire ship revolves slowly in the opposite direction. This rotation of the ship, which continues as long as the turbogenerator turns, is very desirable, because it makes the condensed fluid in the cooler flow to the outer rim, whence it can be conveniently pumped back to the heat exchanger. Moreover, the crew in the toroidal living quarters will feel at least a little "gravity," simulated by the centrifugal force. The thrust chamber, with propellant tanks, will be mounted in such a way that the thrust force always

goes through the center of gravity of the entire ship. The landing craft for Mars will be attached to the thrust chamber unit, with the thrust vector pointing through its center of gravity. The thrust vector will usually be parallel to the tangent of the trajectory.

Flight Path

The flight path of a space ship with an electric propulsion system differs from that of one powered by chemical rocket motors. The acceleration of an electric ship is only a small fraction of 1*g*. The propellant consumption and mass ratio are smaller than they are in a chemically powered ship. The time of propulsion is much longer. As is mentioned in a preceding paragraph, the electric propulsion system operates during the entire trip, except for a few powerless periods of short duration which are needed for corrective maneuvers. The trajectory of the electrically powered ship will not be an elliptical path but segments of several spiral paths.

At first, the ship spirals around the earth (Fig. 3), and its distance from the satellite station increases very slowly (after 2 hours, it will be not more than 20 miles away). After 100 days of steady spiraling, its distance from the earth will be 100,000 miles—about halfway to the moon—and it will have completed 376 revolutions around the earth.

A few days later, its speed and its distance from the earth will have become so great that the ship is no longer restrained by the earth's attractive force. Its trajectory will flatten out and make a transition to a large spiral around the sun (Fig. 4). Its speed continues to increase, as does its distance from the sun.

On the 195th day, the thrust unit will be rotated through 180 degrees, and the ship will start to decelerate. If it did not, it could never be captured by the Martian gravitational field. The deceleration leads the ship gradually into an inward spiral about the sun.

On the 276th day, the thrust will be turned again to acceleration, and this last maneuver carries the ship gently into the Martian ellipse. It arrives there on the 347th day. If the entire trip has been timed correctly, the ship will approach a point on the Martian ellipse where Mars is located at that time. If the ship should arrive too late or too soon, it will merely turn its thrust vector slowly toward the sun or away from the sun. By doing this, it manages, with overspeed or underspeed, to stay in the Martian ellipse. In the first case, it will approach Mars from the rear; in the second, it will be approached by Mars. The approach of the ship to the Martian ellipse and the capture by the planet's gravitational field are shown in Fig. 5. A few thrust maneuvers, which are indicated in the figure, will be necessary to direct the ship into a spiral around the planet. Otherwise, it would crash on Mars or pass the planet in a hyperbolic trajectory.

On the 402nd day, the ship will have descended on its spiral to an altitude of 600 miles above the surface of Mars. The crew shuts off the motor and prepares for the exploration of the planet. The correct time to start the return trip will still be 472 days away. This long waiting period gives the crew ample time to observe Mars closely by telescope

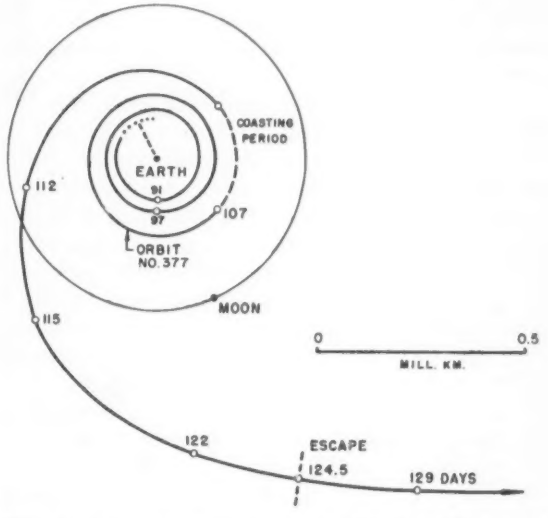

Fig. 3. Trajectory of space ship during first 129 days of its journey from space station to Mars.

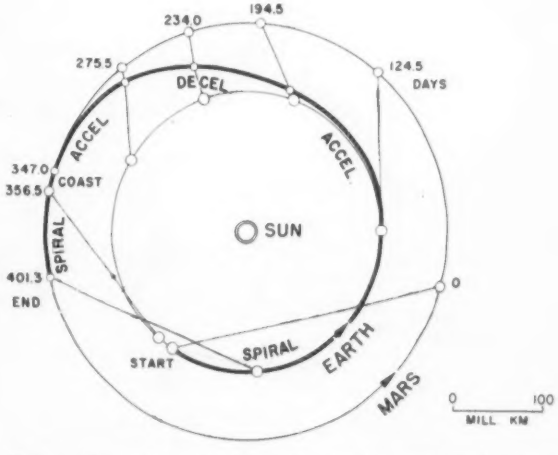

Fig. 4. Trajectory of space ship in its complete journey between space station and Martian ellipse.

and rocket probes, to descend to its barren surface with a winged landing craft, to explore its landscape and study its mysteries, and, finally, to return to the orbiting space ship by means of the rocket-powered central part of the landing craft.

Return Journey

The trip back to earth will be similar to the earth-Mars trip. It will begin with 42 days of spiraling around the planet. A decelerating period follows, which puts the ship into an inward spiral around the sun. Subsequent acceleration adapts this spiral to the earth's ellipse. A few capture maneuvers follow, and a narrow spiral around the earth ends the long trip. After a total time of 3.25 years, the crew arrives again in the orbit of the satellite station. A short shuttle trip takes them down to earth.

The continuous operation of the propulsion system makes the guidance of the space ship easy. At no time will there be a need for unusual accuracy of presettings or aiming. Corrections can be introduced at any time as soon as the trend toward a deviation becomes noticeable. During the spiraling around the earth or Mars, for example, a period of powerless orbiting can be introduced in case a time delay should be needed. If the ship should be late, the crew can gain time during the spiraling phase by opening the throttle a little more.

Nor will navigation impose insurmountable problems. The ship will keep a constant watch of the earth, Mars, Venus, Jupiter, and the sun. The directions of these celestial bodies with respect to the direction of one of the fixed stars will be continually measured and recorded by automatic star trackers. The actual positions of the sun and the planets in a coordinate system that is fixed to the stars are accurately known from an astronomical almanac. With these two sets of data, the position of the ship at any given moment can always be found. In fact, the ship's coordinates are continuously computed from the star tracker readings and compared with the expected coordinates. If any deviation should occur, corrective measures will be taken immediately.

Problems and Their Solutions

In spite of the fact that relatively simple techniques are available by which a space ship can be propelled, guided, and navigated through interplanetary space, a number of questions remain which appear far more difficult to solve. Meteors and cosmic rays present a danger that is unknown to earth-bound men, who are well protected by the atmospheric shield. Maintenance of an artificial atmosphere, in order that human beings can live and work comfortably within the living quarters and in the space suits, sounds like a tremendous problem. A total travel time of 2 full years' duration spent in the monotonous seclusion of the ship's living quarters may seem to be an insuperable psychological obstacle.

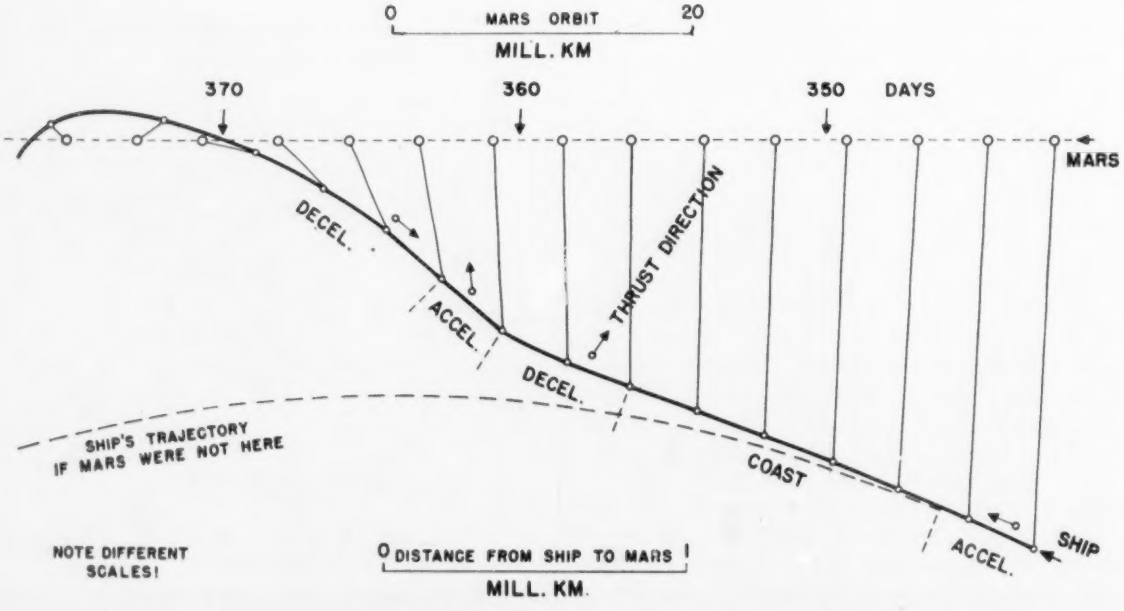

Fig. 5. Approach of space ship to Martian ellipse and capture by the Martian gravitational field.

But things are not as bad as they might seem. Small meteors, which are frequent, can be shielded off by an absorbing meteor bumper. This consists of a thin sheet of metal on the outside of the ship. Larger meteors are very rare. If one of them should punch through the wall of the ship, the doors of the damaged compartment would close automatically, and in most cases the damage could be repaired before a real disaster developed. If a vital part of the ship's machinery should be destroyed, the crew would abandon that ship and board one of the others (there will be a total of about ten ships traveling together in one expedition). If a man should be hit—well, the probability of such an accident is comparable to the probability of a man's losing his life on this earth in some kind of accident.

We still know little about the dangers of cosmic radiation in outer space. But we do know that these dangers are much less than was previously assumed to be the case, and we may be confident that ways and means of providing efficient protection will be available before the first trip to Mars begins. After all, the manned satellite station will represent an excellent research laboratory in which to study all the effects of outer space, including weightlessness, artificial atmosphere, and life in confined quarters. By the time the first space ship leaves the satellite for Mars, its voyage will be much better prepared, in every respect and detail, than were many famous and successful expeditions in the past. The probability of safe return will be greater for the spacefarers than it was for many a daring and courageous team who set out in the past to discover new lands.

The crew on an interplanetary ship will have more comfort and more space in which to move around than the crew on a modern submarine. They will be in constant contact with the earth by means of radio and television. The men who are selected for the expedition must be in excellent health and must have great stability. They will be persons of the scientific type who combine the love of adventure with the craving for scientific knowledge—men who can set aside their personal desires in favor of the idea of a great technical and scientific achievement. A man of this nature will not mind spending two quiet years traveling aboard a space ship. In his normal life, such a man always carries with him a backlog of unfinished scientific work which he cannot find the time to complete. The prospect of being given the opportunity of two full years of undisturbed time in which to study and work on his pet projects will be for him one more dream come true when his space ship takes off for its long voyage to Mars.

Balanus-Fouled White Shrimp

A female white shrimp (*Penaeus setiferus*) fouled by a barnacle (*Balanus amphitrite niveus* Darwin) on its first abdominal segment, 1 millimeter to the right of the mid-dorsal line, is shown on this month's cover. The specimen is one of four that were collected in February and March 1957; one was collected by Gordon Gunter of the Gulf Coast Research Laboratory, Ocean Springs, Mississippi, at the mouth of Ocean Springs harbor, Biloxi Bay; the other three were collected by C. E. Dawson of the Bears Bluff Laboratories, Wadmalaw Island, South Carolina, in the Edisto River system in South Carolina.

In his report on the discovery Dawson wrote [*Science* **126**, 1068 (1957)]: "The capture of four fouled shrimp from the Atlantic and Gulf coasts within a short space of time suggests that careful observation of winter shrimp catches may reveal numerous instances of this association between *Balanus* and *Penaeus*. Analysis of the growth of attached *Balanus* might yield information on winter molting frequencies of individual shrimp."

The Scientist in Contemporary Fiction

BENTLEY GLASS

Dr. Glass, who is professor of biology at Johns Hopkins University, Baltimore, Maryland, received his A.B. and M.A. degrees from Baylor University, and his Ph.D. from the University of Texas. He has taught at Stephens College (1934–38), Goucher College (1938–48), and Hopkins, where he has been since 1948. Dr. Glass is a member of the editorial board of Science *and* The Scientific Monthly, *editor of the McCollum-Pratt Symposia, and editor of the* Quarterly Review of Biology.

THE scientist, as distinct from the inventor and the doctor, has not figured large in the pages of fiction until the current century. In recent years, however, there has been a burgeoning of fiction in which the character of the scientist has played a part. Scientists may be pardoned for exhibiting at least a mild interest in this presentation of themselves and their profession before the public, and so, without my making any pretense of offering an exhaustive survey of contemporary fiction or having read as background all earlier novels centered around scientists, it may be of interest to set down some observations derived from cursory summer reading. Perhaps others may enlarge on my comments.

Novels with a scientist as protagonist seem to fall into three categories. First are the science fiction stories and the "whodunits"—I hope devotees of the first-named will pardon the lumping of them with the latter. In both of these types of fiction the interest is solely, or almost solely, in plot. The scientist himself is a daemon, a *deus ex machina,* a detective, or a criminal who moves the plot along. Of such novels there is little to say in the present context, since they add almost nothing to the serious portrayal of the scientist in fiction. I shall even forbear, though with difficulty, from commenting on the recent discussion of the reasons why scientists—so many of them—like to read novels of this sort (*1*).

The two other types of novels with scientist characters are best understood in the light of their archetypes. First in point of literary time came those novels that deal with science as a social force, with the impact of science on current life and the scientific Utopias of the future. Later—a far less frequent kind of novel—came stories centered around the personality of the scientist and his individual struggle to gain insight, to conquer difficulties, and to grapple with the personal moral and social problems thrust upon him by his chosen way of life. The choice of archetypes is easy, although perhaps other readers in this field might choose slightly different ones. For the novels dealing with the impact of science on society, the selection is almost unavoidably some one of the novels of H. G. Wells—almost any one will do, since they are all practically alike in their portrayal of the scientist. For the second sort, the choice falls on Sinclair Lewis' *Arrowsmith,* for reasons that will become apparent, although other persons might prefer one of the pertinent novels of Aldous Huxley or Philip Wylie. However that may be, against the background of *Men Like Gods* and of *Arrowsmith,* and by their standard of achievement, we can evaluate contemporary efforts to portray the scientist in fiction.

Science as a Social Force

It was H. G. Wells, at least more than any other, who first, in his scientific short stories and novels, undertook to portray the scientist. For Wells, however, science is the creator of Utopia, and the people of Utopia are never quite real flesh and blood. Wells at best had little gift for the creation of living people. As Somerset Maugham has recently written of him:

> His theory of the novelist's function allows him to digress abundantly, which, if you are interested in the characters and their behavior, can hardly fail to arouse in you some impatience. One day . . . he made the remark: "I am only interested in people in the mass, I'm indifferent to the individual." . . . During the course of his life he came in contact with a great many people, but with rare exceptions, though consistently pleasant and courteous, they made no more impression on him than the "extras" who compose the crowd in a moving picture.
>
> I think that is why his novels are less satisfactory than one would have liked them to be. The people he puts before you are not individuals, but lively and talkative marionettes whose function it is to express the ideas he was out to attack or to defend. They do not develop according to their dispositions, but change for the purposes of the theme. It is as though a tadpole did not become a frog, but a

squirrel—because you had a cage that you wanted to pop him into. H.G. seems often to have grown tired of his characters before he was halfway through and then, frankly discarding any attempt at characterization, he becomes an out-and-out pamphleteer. One curious thing that you can hardly help noticing if you have read most of H.G.'s novels is that he deals with very much the same people in book after book. He appears to have been content to use with little variation the few persons who had played an intimate part in his own life. (*2*).

What is here said of H. G. Wells' characters in general applies with special force to his scientists. They are indeed bloodless creatures, mouthpieces preaching the New Utopia—a tiresome lot whose very insistence defeats their author's purpose. Consider, for example, the reply of Urthred in *Men Like Gods,* a typical example of Wells' scientific fiction, to the charge of a transplanted earth-man that the scientific and social order of Utopia will lead, in the absence of struggle and competition, to degeneration:

> The gnawing vigor of the rat, the craving pursuit of the wolf, the mechanical persistence of wasp and fly and disease germ, have gone out of our world. That is true. We have obliterated that much of life's devouring forces. And lost nothing worth having. Pain, filth, indignity for ourselves—or any creatures; they have gone or they go. But it is not true that competition has gone from our world. Why does he say it has? Everyone here works to his or her utmost —for service and distinction. None may cheat himself out of toil or duty as men did in the age of confusion, when the mean and acquisitive lived and bred in luxury upon the heedlessness of more generous types. Why does he say we degenerate? He has been told better already. The indolent and inferior do not procreate here. And why should he threaten us with fancies of irruptions from other, fiercer, more barbaric worlds? It is we who can open the doors into other universes or close them as we choose. Because we know. We can go to them—when we know enough we shall—but they cannot come to us. There is no way but knowledge out of the cages of life . . . What is the matter with the mind of this man?
>
> These Earthlings are only in the beginnings of science. They are still for all practical ends in that phase of fear and taboos that came also in the development of Utopia before confidence and understanding. Out of which phase our own world struggled during the last Age of Confusion. The minds of these Earthlings are full of fears and prohibitions, and though it has dawned upon them that they may possibly control their universe, the thought is too terrible yet for them to face. They avert their minds from it. They still want to go on thinking, as their fathers did before them, that the universe is being managed for them better than they can control it for themselves. Because if that is so, they are free to obey their own violent little individual motives. Leave things to God, they cry, or leave them to Competition. (*3*).

Perhaps there is a lesson for us of the atomic era in these prophetic words. Many words spoken in recent times seem little more than an echo of them. But, whether prophetic or not, it is scarcely deniable that this sort of harangue does nothing to make Urthred a living character, particularly since the words quoted are but a small part of many pages of similar musing. Mr. Barnstaple, in the same book, is the thinly disguised voice of Wells himself, the nonscientist observer, and worshipper, of the achievements of the new religion. He is the chief character in the book, yet there is little more substantial to him than to Urthred. For Wells, all value lies in the plot and in the message of science. The scientist himself is the dedicated tool, the impersonal means to a magnificent end.

Personality of the Scientist

Worlds away from any such portrayal of the scientist is that achieved by Sinclair Lewis in *Arrowsmith* (*4*). There are some stereotypes in that novel, too, particularly the pseudoscientists Drs. Tubbs and Holabird; but the real scientists stand out as unforgettable individuals—Max Gottlieb first of all, the gaunt apostle of science; Gustaf Sondelius, roistering, vehement, enemy of rats and fleas; Terry Wickett, the profane, skeptical, iconoclastic realist, a bitter critic, a true friend; and Martin Arrowsmith, humble, unsure of himself, but now and again caught up in "the happiness of high taut insanity" that every experimenter knows when the big experiment succeeds, the exaltation that keeps a scientist at his work through all the years of drudgery and disappointment. Each of these characters presents a facet of the scientist; each of them has his blind side, and none of them knows all we mean by *science.*

Take Gottlieb first. "Gottlieb, the placidly virulent hater of religious rites, had a religious-seeming custom. Often he knelt by his bed and let his mind run free. It was very much like prayer, though certainly there was no formal invocation, no consciousness of a Supreme Being—other than Max Gottlieb." Gottlieb's definition of a scientist is one of the most eloquent assertions ever made about science. Contrast the earthiness of Gottlieb with the vaporous idealism of Urthred in the previous quotation:

> To be a scientist—it is not just a different job, so that a man should choose between being a scientist and being an explorer or a bond-salesman or a physician or a king or a farmer. It is a tangle of

very obscure emotions, like mysticism, or wanting to write poetry; it makes its victim all different from the good normal man. The normal man, he does not care much what he does except that he should eat and sleep and make love. But the scientist is intensely religious—he is so religious that he will not accept quarter-truths, because they are an insult to his faith.

He speaks no meaner of the ridiculous faith-healers and chiropractors than he does of the doctors that want to snatch our science before it is tested and rush around hoping they heal people, and spoiling all the clues with their footsteps; and worse than the men like hogs, worse than the imbeciles who have not even heard of science, he hates pseudo-scientists, guess-scientists—like these psychoanalysts; and worse than those comic dream-scientists he hates the men that are allowed in a clean kingdom like biology but know only one text-book and how to lecture to nincompoops all so popular! He is the only real revolutionary, the authentic scientist, because he alone knows how liddle he knows.

He must be heartless. He lives in a cold, clear light. Yet dis is a funny t'ing: really, in private, he is not cold nor heartless—so much less cold than the Professional Optimists. The world has always been ruled by the Philanthropists: by the doctors that want to use therapeutic methods they do not understand, by the soldiers that want something to defend their country against, by the preachers that yearn to make everybody listen to them, by the kind manufacturers that love their workers, by the eloquent statesmen and soft-hearted authors—and see once what a fine mess of hell they haf made of the world! Maybe now it is time for the scientist, who works and searches and never goes around howling how he loves everybody!

But once again always remember that not all the men who work at science are scientists. So few! The rest—secretaries, press-agents, camp-followers! To be a scientist is like being a Goethe: it is born in you. Sometimes I t'ink you have a liddle of it born in you. If you haf, there is only one t'ing—no, there is two t'ings you must do: work twice as hard as you can, and keep people from using you. I will try to protect you from Success. It is all I can do. So . . . May Koch bless you!" (*4*, pp. 279–280).

Martin Arrowsmith, new in New York, from his windows in the magnificence of the McGurk Laboratories, looks out on the Woolworth Tower and down on the feverish streets. To the west he sees tall ships riding, bustling tugs in the river. All the world goes by, and "suddenly he loved humanity as he loved the decent, clean rows of test-tubes," and he prayed then the prayer of the scientist:

> God give me unclouded eyes and freedom from haste. God give me a quiet and relentless anger against all pretense and all pretentious work and all work left slack and unfinished. God give me a restlessness whereby I may neither sleep nor accept praise till my observed results equal my calculated results or in pious glee I discover and assault my error. God give me strength not to trust in God! (*4*, pp. 280–281).

Sondelius, burning with the fever of the bubonic plague, his face and tongue swollen, his voice weak, babbling:

> Gottlieb is right about these jests of God. Yey! His best one is the tropics. God planned them so beautiful, flowers and sea and mountains. He made the fruit to grow so well that man need not work —and then He laughed, and stuck in volcanoes and snakes and damp heat and early senility and the plague and malaria. But the nastiest trick He ever played on man was inventing the flea. (*4*, p. 381).

What Sinclair Lewis built up, in the characters of these several, unique scientists, could never have been poured into a single mold. Together, they exemplify the spirit of science diversified by personality. Individually, they reveal in their endeavors the nature and methods of science in something of their real variety.

A further reason for the novelist's success in his effort to portray science in *Arrowsmith* lies in the fact that the plot is not essentially the development of a scientific theme, but rather the impact of the pursuit of science on the people involved. Desperation and frustration, disillusionment, anger, and scorn walk these pages beside enduring love and tender devotion, self-sacrifice, and heroism. Here indeed, "he that loseth his life shall find it"—Leora and Sondelius, dead of the plague; Gottlieb, stricken and paralyzed, but living in the worship of the young scientists he had trained; Martin Arrowsmith, forsaking wife and child to be free to study and work.

The Scientist in Contemporary Novels

So much for the prototypes. In recent years the number of novels in which a scientist is the leading character, or one of the leading characters, has rapidly multiplied. Quite clearly this is a sign of the awakening realization of the dependence of modern society upon scientific understanding, and of the appalling effect of new scientific discoveries upon established ways of life. Witness the plots of some of these novels. *The Secret* by Michael Amrine (1950) (*5*) deals with the reactions of an atomic physicist to wartime secrecy in atomic research and his participation in the postwar struggle to get the conduct of research upon atomic energy away from the control of the military and into the hands of

civilians. The plot of *The Big Secret,* by Merle Colby (1949) (*6*), is practically identical.

In Nigel Balchin's novel, *Who Is My Neighbor?* (1950) (*7*), the scientists are bacteriologists who have discovered a secret way to control infectious disease—it is not at all clear what sort of method it is—that might save millions of human lives; but the government forbids them to publish this discovery because an enemy, in time of war, might put it to dreadful use. The scene is London instead of Washington, but the crisis is the same: the conflict between the scientific ideal of free and unrestricted international diffusion of new knowledge, and the fears of national-minded men in the face of overwhelming danger resulting from the applications of science to war. *The Diplomat* (1950), by James Aldridge (*8*), is another British novel. Here the plot revolves around the mental struggle of a micropaleontologist whose work in Iran has made him an authority on Near Eastern conditions and has embroiled him in the struggle of East and West over the oil so desperately needed by each side for military security. The conflict is again that between a man's scientific conscience and those older loyalties to mother country and to the people who speak his own language. Nevil Shute, who has a considerable number of well-written novels to his credit, has added *No Highway* (1948), in which a theorist in aerodynamics struggles not only with the problems of supersonic flight but also with bureaucratic failure to comprehend and act in time (*9*).

Another pair of novels, *The Fire and the Wood,* by R. C. Hutchinson (1940) (*10*), and *Nothing So Strange* (1947), by James Hilton (*11*), deal with the entanglement of scientists, working abroad, in the mesh of totalitarian politics. The theme is in essence the same as in the novels previously mentioned. The characteristic of the totalitarian attitude toward political science is the subjection of science to political authority, the prostitution of scientific integrity to specious ends. The Nazis made this clear with their theories of racial purity and racial superiority, and the Communists by their insistence on the reality of an inheritance of acquired characteristics. It will, therefore, be strange if the future does not bring forth a companion to the novels just named, one in which the plot will focus on Communist science rather than on Nazi science.

In *The Business at Blanche Capel* (1953), by Bryan Morgan (*12*), the plot is the theft of a deadly virus from a biological warfare center in England by a scientist with Communist ties. It is a typical mystery story, and although the author obviously knows his way around a laboratory, the plot is the thing. The Communist is a shadow of no substance, and the hero and heroine of the story, also scientists, are motivated chiefly by sex.

In none of these novels does there appear to be any profound understanding of the nature of science itself, nor any characters who portray the true feeling of participation in a mighty enterprise. The plot is never a man's part in a great human adventure that is at least half revealed, but rather it is his embroilment in political conflict, in the defense of scientific freedom. There is unquestionably the stuff of a fine plot here—although it gives evidence of being already overworked—but the elaboration of such a plot requires little or no development of the character of scientist *qua* scientist. The chief matter is the man's integrity. Consequently these protagonists of science seem only a slight level above the "scientists" in certain detective stories and murder mysteries—for example, *The Clock Strikes Thirteen,* by Herbert Brean (*13*), or *The Bat That Flits,* by Norman Collins (*14*)—"scientists" whose sole service is to provide a suitably unusual setting for death and violence. Even more amusing is the "scientist" in *It Happens Every Spring* by Valentine Davies (*15*), whose author knows so little about what to do with him as a scientist that in order to keep up the reader's interest the hero is transformed into the winning pitcher of a World Series baseball team.

A different note is struck in Mitchell Wilson's *Live with Lightning* (1949) (*16*). The author knows the laboratory background of the physics student and the unceasing absorption in work and ideas that makes the personal relations of scientists with their families and friends so difficult. The people live and, what is more, they grow. As for science itself, there is an interesting passage which throws light on the author's interpretation and understanding:

> A long time ago, perhaps from the very beginning of life, Erik had sensed the struggle for existence of all things. All about him there was war, incessant war, not between men, but on a far more savage level: the war of life to survive in spite of every physical law that decreed its death. Life was fragile, tentative, an irrational accident of a few coincidences, a turbulent little eddy in the awesome torrent roaring down the broad valley mapped by thermodynamics. In the silent dark cold vastness of time and the universe, life was no more than a rosebud; but it was stubborn, and its doomed possessors gripped that tiny fragile softness and stared defiantly at the unresponsive enemy night.
>
> . . . There was death on sunlit summer mornings, death on soft spring nights, a thousand deaths, a million deaths.
>
> Sooner or later, one asked *Why*? . . . Some, the

looters, ignored the foe to rape, steal, and lust behind their own lines; but far out in the darkness, there were always the scouts advancing into the unknown terrain. Whether by groups or in solitude, out they went to stalk the stars; to haunt, harass, and harness the maniacal vitality in the minuscule jellies; to probe the great molten ball beneath their feet that spun them all lazily through silent space.

This was the true war, and men drifted into the ranks without banners, without slogans, without heroism. They came naively, asking "But what else is there to do?" . . .

It was a lonesome war for the warriors. With all the sublimity of their goal, they were still only men —soft, pliable, spindly, tainted with every weakness of the species. Imperfection plagued them like lice. Because they were only human, they scratched themselves and writhed in their discomfort while they advanced. There were no individual prizes to be won except for the feeling that one's task was well done. And even this was a medal easily tarnished by experience. To become and to remain the kind of man that one respected was almost impossibly difficult. It required a discipline that was too often self-mutilation. Courage for that was hard to come by, so that the external war was fought again in miniature in the heart of every man. (*16*, pp. 397–398).

Another interesting novel, with full-bodied characters is *The Betrayers* (1953), by Ruth Chatterton (*17*). The plot is a complex one, yet taken almost entirely from real life. There is a senatorial demagogue who is out to "get" a nuclear physicist who, he charges, is a Communist. A brilliant woman lawyer, wife of another senator, is convinced of the scientist's innocence and successfully undertakes his defense. Yet the physicist, through an idealistic conviction that peace can only be ensured to the world if both armed camps are kept equally balanced in the quest for military security, has long since been a purveyor of atomic secrets to the enemy. Only his suicide is capable of clearing the air.

Two novels more recent than any of the foregoing deal with the problems of conscience harassing the nuclear physicists who worked to develop the atomic bomb. The British novelist, C. P. Snow, in *The New Men* (1955) (*18*), lays his scene at Harwell (or Barford, as he calls it). The story moves jerkily, with unclear development, and revolves more around fraternal love and anger, marital infelicity, and sharp ambition than around conscience, so that the denouement seems ungrounded and unreal. Perhaps, as much as anything, this is a fault of the style, which is conversational to pedestrian, and never moves the spirit. The relative failure of this book to fulfill its promise is the more regrettable because, by experience and training, the author would seem to have been better qualified to write of scientists than most.

A sharp distinction is exhibited by Aldous Huxley's latest novel, *The Genius and the Goddess* (*19*), which has two principal characters who are scientists. Huxley's concern is with character and personality, but the central figure which so dominates the book that all others recede into the background is Katy Maartens, the goddess, the genius's wife. Henry Maartens himself is a gross caricature, a mixture of "fetus, genius, half-wit and hungry lover," in which the element of genius is hardly adumbrated. The narrator of the story, who reminisces about his youth, is the scientist John Rivers, and the novel centers on the sensual aspects of sex experience. Scarcely a page is devoted to any significant relation of man either to science itself or to the social impact of science. One could go through the book and exchange science for architecture with very little inconsistency.

A book, on the other hand, which comes close to *Arrowsmith* in delineation of a scientist's character, and which cannot fail to move the reader with its somber beauty and deep, unforgettable emotion, is *The Accident* (1955), by Dexter Masters (*20*). In 1946 Dexter Masters was coeditor of *One World or None* (*21*). During that same year, at Los Alamos, one of the nuclear physicists who had a part in the development of the bomb, Louis Slotin, met with a fatal burst of radiation in an experiment that went wrong. Nine days later he died. This book is a description of those days—Masters makes it seven days. That is the entire plot—one man, a scientist, slowly disintegrating in the aftermath of a flare of nuclear energy, so minuscule beside Hiroshima and Nagasaki. In the thoughts of Louis Saxl, the protagonist, and in the thoughts of his nurse and doctors, of his friends, of his family, and of Theresa, the girl he would have married in just two weeks, one reconstructs his life up to the fatal point. What makes a scientist, and how a boy grows into one; the scientist's love of the constancy, honesty, and integrity of science, and his conflict with the military mind; and the conflict of conscience, scientific and social, of the atomic scientist—these are portrayed with eloquence and insight. And in the end, when no one can stay death any longer, the work resumes—the medical investigation, the experiments, and the military production of yet more bombs. Los Alamos!

Conclusion

Space does not permit me to say more of other examples of the scientist in fiction, but at least mention should be made of the fine portrayals in

certain historical novels, such as that of Galileo in Zsolt de Harsanyi's *The Star-gazer* (*22*) and of Ignaz Semmelweis in Morton Thompson's *Cry and the Covenant* (*23*). Yet these are essentially like other historical novels, recreating the picture of a past graphically and often with insight, but not creating in fiction the figure of the modern scientist, the threads of his development, his problems and temptations, his struggle for integrity, his yearning to possess the stars, and his sudden, frightening command of power to change the face of the earth and the lives of millions of men breathing now or still unborn.

The lesson for the novelist who would dare to delineate such a figure is, it seems to me, set forth clearly by the contrast between the pallid characters of H. G. Wells and the flesh-and-blood characters of Sinclair Lewis. The people—not the plot—after all make a great work of fiction. Who reads the social novels of the Victorian era nowadays, even though Charles Reade and others wrote many a good one? The concern with the great problem of the power of science and of the control over it lends itself to a vigorous and gripping plot; but the scientist of fiction who will endure is the one who becomes real to you as you read. This is why the musicians in fiction have fared so much better than the scientists, with Rolland's *Jean Christophe* and Mann's *Doctor Faustus* to set the key.

We face here the eternal dilemma of the great novel and the reason for the scarcity of such. The great novelist must not only be able to write, he must know whereof he writes. The novelist who would venture to portray a scientist as a leading figure must probe not only the depths of human personality and the breadth of human relationships, but over and above that he must somehow have acquired an appreciation of the prevailing outlook of the scientist upon life and of the methods and spirit of science itself. How hard it is to achieve this, the isolated stature of *Arrowsmith* amply testifies. Perhaps only those who are wholly dedicated to science could write with finality of such a life; and they have neither the time nor the ability. Science itself has claimed them (*24*).

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The Last Geographic Frontier: the Sea Floor

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MANY persons fall into the error of believing that we live in an advanced age, with all exploration and frontier life far behind us; that, geographically at least, all the great discoveries have been made, all the frontiers have been crossed, and even the highest mountain has been finally conquered. It is refreshing, then, for those of an adventurous bent to learn that there is one branch of science and exploration which is still in its infancy—a branch where great peaks and ranges of mountains, deep basins and trenches, and mighty fault zones are being found today, with still others waiting to be discovered. This branch of science is marine geology. The sea floor, especially the deep-sea floor, provides this realm for fresh discovery.

A summary of present knowledge and development of marine geology, if complete, would fill a large textbook, as indeed it has. Shepard's *Submarine Geology,* published in 1948 (*1*), was the first English language textbook in the field; it was followed 2 years later by Kuenen's *Marine Geology* (*2*). Both of these books summarized the field as of the dates of publication. Another excellent summary, treating primarily of deep-sea geology, was published as a long paper by Wiseman and Ovey in 1950 (*3*). Rather than reiterate these excellent summaries, I prefer to discuss some of the more important developments and discoveries which have been made in recent years, giving only enough background to inform the nongeologist reader. These advances in knowledge are mainly in relation to the structure, topography, and sediments of the ocean basins.

Historical Development

The topography of the sea floor is the subject on which the science of marine geology is based. The first essential of most work is an accurate chart. The era of accurate chart construction began in 1569 when Mercator published his world map, which was based on the well-known projection principle which now bears his name. Gradually the outlines of the continents and details of their coast lines were delineated. Because the charts were intended primarily for mariners, little work was done on charting the depths of the oceans, save in those near-shore areas which were important to navigation. In addition, geology, as a physical science, was in its infancy as late as the early 19th century. The few geologists then active occupied themselves almost exclusively with mapping the land world and developing basic geologic concepts. As a result, the sea floor was almost completely neglected as an area of investigation.

Marine geology, for all practical purposes, had its beginning with the voyage of the British ship *H.M.S. Challenger,* which made a round-the-world voyage of exploration between 1872 and 1876. Its reports, especially the volume on marine sediments by Murray and Renard, are still referenced classics (*4*). As it had on most branches of science, World War II had a great impact on exploration of the sea floor. An immense amount of information, some not yet completely digested, was added to our existing knowledge of the sea floor by the navies of the world; some of this material is still classified, but much has already been studied, analyzed, and incorporated into the literature and charts of the sea floor.

Since World War II, the principal civilian organizations in the United States to conduct sea-floor studies have been the Lamont Geological Observatory, the Chesapeake Bay Institute, and Woods Hole Oceanographic Institution, on the East Coast, and the Scripps Institution of Oceanography, the Allan Hancock Foundation, the University of Southern California, and the University of Washington, on the West Coast. The principal Govern-

ment organizations have been the U.S. Navy Hydrographic Office, the U.S. Coast and Geodetic Survey, the U.S. Geological Survey, and the U.S. Navy Electronics Laboratory. Outside the United States the contributions of Cousteau's group in France, of Cambridge University, and of the Swedish and Danish Deep-Sea Expeditions have been especially noteworthy.

The method of constructing accurate bathymetric charts, which are the most essential tool of the marine geologist, involves sounding the sea floor and then contouring the resulting subsurface depths. Until World War I, most soundings were made with rope or wire lines or by pressure tubes —small, closed-end tubes in which the air was compressed as the device was lowered (*5*). These methods were very tedious, and it took a great investment in time and labor to produce even a single sounding. The sciences of underwater acoustics and electronics joined forces in the early 20th century and made a break-through discovery—the echo sounder—which revolutionized the field of marine geology. In the early 1900's, Behm in Germany, Langevin and Chilowski in France, and Fessenden and Dorsey in the United States were important in the early development of the echo sounder, although the general suggestion of employing sound for depth measurement was made by a French physicist, Arago, as early as 1807 (*5*). The first line of echo soundings was run by the Centre d'Etudes of Toulon in 1920, and the first echo sounder used by the U.S. Coast and Geodetic Survey was installed on the *Guide* in 1923 (*5*). Gradually, from that time, lines of soundings made by continuously operated echo sounders have permitted construction of reconnaissance-type charts of the deep-sea floor, that area beyond and deeper than the continental slope. In the shallower waters, where commercial and governmental interests are primarily focussed, the charts are usually accurate. Most charts of the deep sea are of a low order of accuracy, and tremendous areas remain to be sounded for the first time.

Many of the findings of science are directly dependent on instrumentation. This is especially true in marine geology because the geologist, except in very shallow waters, can never directly see what he is studying; he can only collect samples and gather data by remote control. Generally speaking, samples of the sea floor are obtained by dragging steel dredges over the bottom, by piercing it with a coring tube, or by picking up material with a device that snaps or closes its jaws on impact with the bottom. Little advance has been made in dredging techniques since they were first employed, and coring by gravity corer has been standard for decades. A real advance in coring was made by Kullenberg with his invention of the piston corer, which allows a core barrel to fall around a piston into the sea floor while unbalanced hydrostatic pressures help overcome the friction of sediment inside the barrel; cores as long as 70 feet have been obtained in this manner. Zenkevich reports that the Soviet research vessel *Vityaz* has taken cores up to 34 meters long; the coring device was not described (*6*). Supplementing these relatively simple techniques, there have been rapid and important advances in geophysical and visual methods which, in the last few years, have caused marked advances in our knowledge of the structure and sediments of the ocean basins.

Seismic exploration at sea has been responsible for the most important advances in marine geology in the past 10 years. Some knowledge about seismic and other geophysical work is necessary as background to understand the study of the sea floor.

Gravity Measurements

After many years of making gravity measurements on the continents, it became apparent that gravity determinations at sea were essential to the complete picture of the balance between the continents and the ocean basins; this condition of balance is termed "isostasy." This work began in 1893–96 on the steamship *Fram* of the Nansen Polar Expedition. A pendulum apparatus was used while the ship was gripped fast in the ice. Later work on the high seas gave some ideas on the values to be expected, but it remained for Vening Meinesz, a Dutch geophysicist, to perfect the instrumentation and, by extensive work from submarines, to give good reconnaissance coverage to the ocean basins (*7*). Vening Meinesz made his first cruise in 1923, from Holland to Java by way of the Suez Canal. During the next 10 years he measured gravity around the world, and his reports in 1932 and 1934 are classics of individual research (*8*). Vening Meinesz proved that there were large positive gravity anomalies (differences between computed and measured values) over all of the deep oceans, but when gravity was computed according to an isostatic reduction method, these anomalies largely disappeared and it was seen that the ocean basins are in balance—that is, in isostatic adjustment—with the continents. Several other interesting and important discoveries were made during these cruises. Vening Meinesz discovered that the island arcs of the East Indies and West Indies are characterized by great negative and positive anomaly strips and that there are huge negative anomalies over the deeps of the open ocean.

During the earlier days of the theory of isostasy there was considerable discussion about whether

the compensation for topography was local or whether it was spread out to each side and could be called regional. It appears at this time that both ideas are valid.

Gravity work at sea has been continued since World War II, principally by members of the Lamont Geological Observatory group, led by Ewing. This group occupied more than 2000 gravity stations, in submarines, from 1947 to 1953 (*9*). An important example of such work is the investigation of the change from continental to oceanic crust at the continental margins (*10*).

Seismic Measurements

The pioneer work in explosive seismology at sea was done in the 1930's by Ewing's group at Columbia University (*11*). The method depends on the study of elastic waves, generated at the surface by explosives and transmitted through various layers of sediment and rock. The travel times are dependent on the sediment or rock type and on the paths taken by the waves. At the present time, four institutions are doing seismic work at sea: Columbia University (Lamont Geological Observatory), Scripps Institution of Oceanography, Cambridge University, and the Woods Hole Oceanographic Institution. The objectives of these studies are to measure the thickness and determine the physical properties of the unconsolidated sediments on the sea floor and to determine the properties and structure of the upper part of the earth's crust. This is extremely important in the study of the evolution of the earth, the formation of the continents, and the geologic history of the ocean basins.

Ewing and Press began reexamining natural earthquake waves in 1950 in an attempt to reconcile differences in the structure determined from study of natural and artificially induced waves. They were successful, and thus an important and powerful new tool for examining crustal structure was placed in the hands of the geophysicists. This applied especially to areas not presently studied by explosive seismology or to areas inaccessible to that technique (*12*).

Heat Flow Measurements

In the last 10 years, interesting and significant determinations of heat flow through the sea floor have been made by Maxwell and Revelle of Scripps Institution and by Bullard of Cambridge University (*13*). The instrument used is a probe about 10 feet long and 1 to 1.6 inches in diameter. The temperature difference between points near the top and bottom of the probe is measured by a thermistor bridge and amplifier or by thermojunctions connected to a galvanometer. Conductivity of the sediments is measured in the laboratory by means of core samples. The heat flow thus measured through the Pacific sea floor averages close to 40 calories per square centimeter, per year, which is about the same as that from the lands. This value was a surprise, because it had been previously thought that most of the heat flow on land was from radioactive decay of minerals in the "granitic" rocks of the continents; the flow from under the seas was expected to be less because of the lesser amounts of radioactive minerals in the igneous rocks under the sea floors. The reasons for this anomalous flow have not yet been determined, but Bullard, Maxwell, and Revelle think that the simplest explanation is that the original radioactivity of the upper mantle has been concentrated in the crust, allowing the continental heat to escape by conduction, while beneath the sea floor the same amount of radioactivity is still distributed through the mantle and the heat is brought to the surface by convection or high thermal conductivity (*13*).

As a result of the geophysical studies of the past few years, is appears to be proved that the structure of the earth in oceanic areas is simple and quite distinct from that of the continents. In oceanic areas the typical structure is about 5 kilometers of water overlying ½ to 2 kilometers of sediments, which in turn overlie about 5 kilometers of basalt under which the earth's upper mantle, thought to be the heavy rock peridotite, occurs (Fig. 1). It also appears that the same structure occurs in all oceanic areas and that continental-type rocks, formerly thought to be present over much of the Atlantic, do not occur in oceanic basins. Ewing and Press emphasize the special cases which diverge from this picture—mainly mountains (both continental and under-sea), island areas and trenches, and continental margins (*14*).

The thickness of unconsolidated sediments on the ocean floor is much less than was anticipated in view of the probable great age and permanence of the main ocean basins (*14, 15*). Why this is so is an unsolved problem at the present time. Some of the hypotheses proposed include the idea that the lower part of the sediments have been so metamorphosed that their compressional elastic wave velocity is close to that of igneous rocks, or have been so compacted that the velocity has markedly increased.

Much scientific and not-so-scientific thought has been expended on the problem of the permanence or impermanence of the ocean basins. The idea of continental drift, and the ideas about foundered intercontinental land bridges, have been largely discounted as a result of the recent findings, outlined above. The marked divergence between continental

and oceanic structure, the strength of the earth's crust, and the fact that the continents and ocean basins are in almost perfect isostatic balance imply that the oceans are extremely ancient features and that they are permanent as far as the geologic record is concerned (*16*).

The sedimentary record in the sea reinforces this conclusion as far as "foundered continents" are concerned. The radioactive and paleontologic dating of deep-sea sediments indicates that they were laid down long before man appeared on the earth and in the same environment in which we find them today.

The Atlantic Sea Floor

The first bathymetric chart of an ocean—that of the Atlantic, by Maury, in 1855—was based on fewer than 200 soundings taken by hemp line. More recent work in the Atlantic by the German ships *Meteor* and *Altair* resulted in charts on which much of the gross morphology was shown, but it was not until surveying by continuous echo sounder became practical that topography was shown in more than a generalized way. Work since World War II by personnel of Woods Hole Oceanographic Institution, the Lamont Geological Observ-

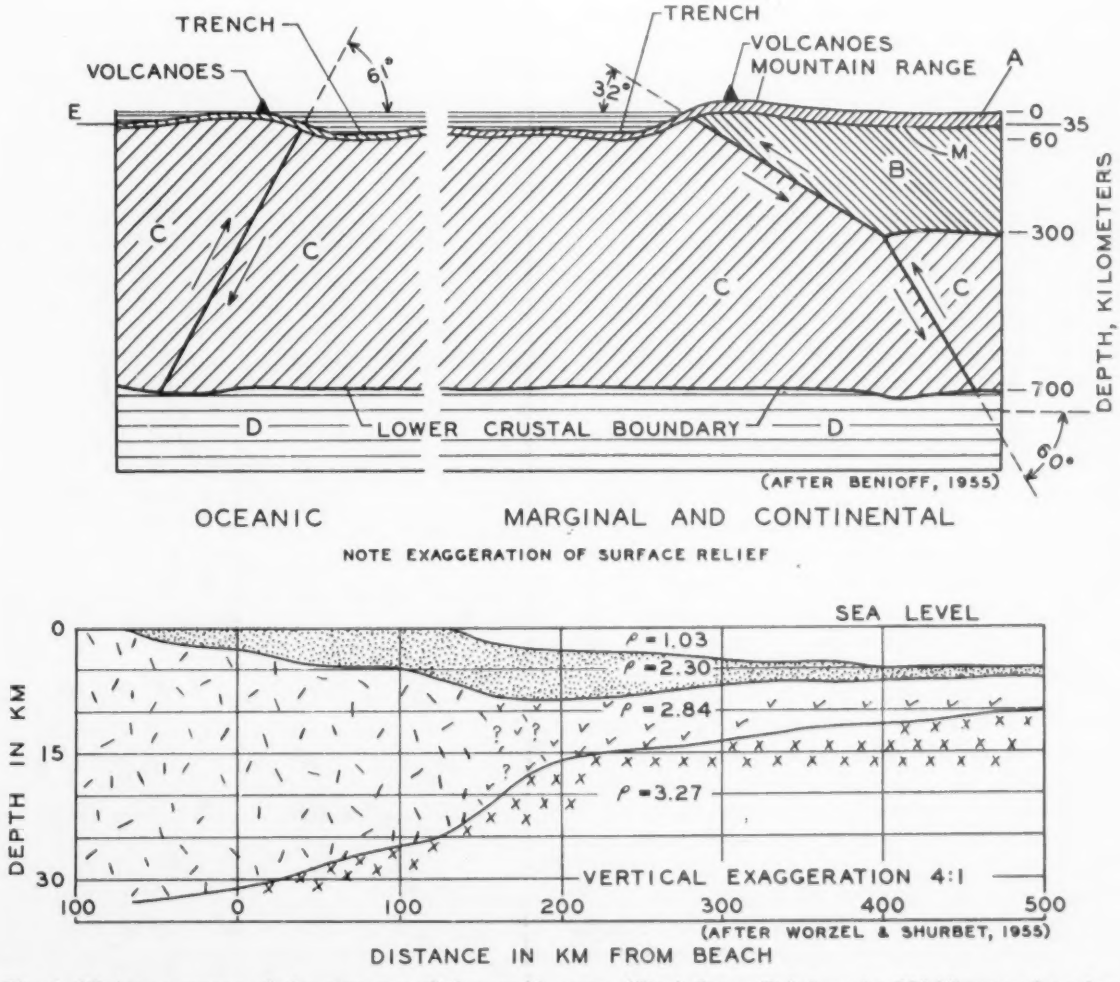

Fig. 1. Modern concepts of the structure of the earth's crust. (Top) Layer D below the 700-kilometer boundary is too fluid to accumulate shear stresses; layer C extends from a depth of 700 kilometers to the Mohorovicic discontinuity in the oceanic realm and to the 300-kilometer discontinuity under the continents (faults in this layer have a dip of about 60 degrees); layer B occurs only under the continents; the oceanic area illustrates the ideas held concerning the relations between the island arcs, oceanic trenches, and the great, dipping fault planes (*30*). (Bottom) The transition of the continental crust to an oceanic crust along a line from Cape May, New Jersey; the densities commonly assumed for each "layer" are shown. In the oceanic area the "layers" are water, sediments, basalt (?), and peridotite (?) (*10*).

atory, Cambridge University, and the Hydrographic Office has added much new information about the topography of the North Atlantic (*17, 18*). These studies have revealed new and important information, especially in connection with the Mid-Atlantic Ridge, submarine canyons, and density currents.

The Atlantic Ocean floor is dominated by the great Mid-Atlantic Ridge, extending from Iceland to about 55 degrees south latitude. Transverse ridges from the main ridge divide the Atlantic into basins. The highest parts of the Ridge reach up to within 1000 fathoms of the surface, and some of the topmost peaks project above water to form islands such as the Azores (*18*).

Along the continental slopes of the North American and other continents there are numerous great canyons, some of which are of the magnitude of the Grand Canyon. The problem of the origin of these great features remains unsolved. It was originally thought that many of them were formed by the erosion of running water during a time when the continental margins were above sea level. When it was discovered that the mouths of many of these canyons were too deep to have been formed in this manner, attention was directed to other possibilities. Daly suggested in 1936 that they might have been eroded under the sea by the action of "density currents" (*19*)—currents containing suspended sediment which flow along the floor of a body of water because of their higher density. The composite, moving collection of sediment and water constitutes the density current, and theoretically any such body should cause both erosion, as it moves along the bottom, and deposition, as the movement slows or ceases.

When large volumes of sediment start to slide downslope, it is thought that, in many cases, the mass of sediment becomes mixed with water to form a density current. The movement might be started by earthquakes or storm waves, or by deposition of a slope to an angle greater than the stable angle of repose for a particular sediment.

Laboratory and theoretical studies, largely by Kuenen, a Dutch geologist, have shown that the concept of density currents is valid (*20*). Whether or not density currents formed the great submarine canyons by erosion is not yet certain, but evidence is accumulating that this process has contributed to their present appearance. At least, much sediment is transported down these canyons from shallow water and is spread across the ocean floor.

If density currents are operative in the sea, then one would expect that sediments, organisms, and other material commonly found in shallow water would be found in deeper water, where they had been transported by density currents. These expectations have proved to be well-founded; in both the Atlantic and Pacific Oceans, deep-water deposits have been found in which shallow-water sands, silts, animals, and plants are imbedded with the clays, or oozes, usually found in the deep ocean. In other words, these are displaced sediments; they have been transported from shallow water, and the most plausible explanation is that they have been transported along the bottom by currents of relatively higher density than that of the bottom water (*21*).

The Grand Banks earthquake of 1929 apparently triggered off a great slide which rapidly became mixed with bottom water to become a density current. This current then flowed downslope at speeds up to 50 miles per hour and, for 13 hours, broke submarine telegraph cables successively, downslope, out to a distance of 300 miles. The current ran out onto the abyssal plain a distance of 600 miles, where it deposited sediments up to 1 meter in thickness (*24*).

The distribution of deep-sea sediments in the oceans was first (1872–76) extensively studied and mapped by Murray and Renard for the *Challenger* expedition (*4*). Other investigators added detail to these original charts, but until the end of World War II the over-all picture remained the same; deposition of sediments in the deep ocean was by the accumulation of mineral and organic material from the waters above the bottom, by more or less vertical settling. In the deeper areas (below about 2400 fathoms) this material is called "red-clay." The sediment in the shallower areas is called *Globigerina* ooze and is formed by the accumulation of the minute shells of the protozoan order Foraminifera, which settle through the water column to form a deposit, on the bottom, which is usually a milky white.

It soon became evident that if one could collect a long enough core of the deep-sea sediments, a continuous history of the deposits far back in geologic time might be obtained. Kullenberg, of Sweden, perfected the necessary equipment when he invented the piston corer, and cores up to 70 feet were obtained. The surprising result has been the discovery that there is, in many areas, only a surficial carpet of the expected deep-sea sediment and that under this thin carpet there is an alternation of thin layers of sediments which could have come only from shallower water (*25*). An example of this occurs in the basins of the deep North Atlantic, where the Lamont and Woods Hole geologists have discovered that vast, virtually level plains have been formed by the action of density currents, and the sediments so deposited may have sloughed off

higher slopes during the lowered sea level of the ice ages. Similar sediments off the Pacific coast are more restricted, due mainly to entrapment in basins just off the California coast (*23*).

Pacific Sea Floor

There are no really accurate charts of the whole sea floor of the Pacific Ocean, and there probably will be none for many years to come. The area is so vast and the sounding lines are so few that, so far, only maps of a reconnaissance nature have been published. In some areas, however, enough data are accumulating so that the shape of the sea floor can be delineated with considerable confidence.

The present status of knowledge of the sea floor in the Pacific Ocean area is such that a surprising amount of evidence of large-scale faulting, mountain building, volcanic activity, and large-scale crustal movements is known; this is a marked departure from earlier assumptions, which, because of lack of information, held that this vast area had been relatively calm during geologic time.

Some of the deep-sea areas where work has been done on a broad scale in the past few years are the Western Pacific, the northern Marshall Islands, the Hawaiian area, the Northeastern Pacific Basin, the Gulf of Alaska, and the great trenches of the Pacific border. Almost nothing is known about the South Pacific Basin, although the Capricorn Expedition of Scripps Institution and the Swedish and Danish Deep-Sea Expeditions have contributed some information.

Menard has demonstrated that roughly 90 percent of the floor of the Pacific Basin is rough and irregular, with an average relief of about 1000 feet, and that about 10 percent of the Pacific Basin is smooth (*26*). He also has shown that most of the smooth area either borders continents or is around existing or drowned islands, where the sediments from the erosion of the islands, plus volcanic products, have smoothed over the normally rough bottom. The departures from this general picture—namely, the great trenches, mountains, and fractured zones—have received much attention in recent years and have furnished much important information in the great structural picture of the earth's crust.

Great Trenches

It has long been known that many island chains are arcuate in shape and that there were remarkable geologic phenomena associated with them. Island arcs are associated with active volcanism and with shallow and deep earthquake activity and are characterized on their seaward side by very deep, curved, and long furrows or trenches in the sea floor. Notable examples are in Indonesia and along the Philippine and Aleutian islands. There are also other trenches which border the Pacific along the coasts of South America and Central America and along the west coast of Mexico (Fig. 2) These tremendous features have a common maximum depth of roughly 35,000 feet, and in them are found all of the greatest depths in the world.

Until recently it was thought that the greatest depth of the oceans was in the Mindanao Trench, off the Philippine Islands; recent discoveries have indicated that this depth, taken by the German ship *Emden,* is not the greatest. The current maximum measured depth is 35,290 to 35,640 feet, in the Mariannas Trench; this depth was recorded by *H.M.S. Challenger,* the modern namesake of the first ship to really explore the deep sea. The second greatest depth is now thought to be about 34,880 feet, in the Tonga Trench of the South Pacific (*27, 28*).

The study of these trenches began more than 50 years ago, but it was not until Vening Meinesz had completed his gravimetric studies and had published his results, in 1934, that it was generally known that these trenches and island arcs were also the location of great, narrow strips of negative gravity anomalies—the greatest departures from isostatic equilibrium on the earth. Active studies of these features are being made at present by scientists from Lamont, Woods Hole, Scripps, and the U.S.S.R. Recently, many of the trenches have been crossed and mapped by echo sounders; some, both in the Atlantic and in the Pacific, have also been studied by seismic methods, and lines of gravity stations have been made over several others.

It is currently believed that most of these great trenches are the result of compression of the earth's outer crust, from which a down-bowed section results. If this down-bowed crust is in a continental-type material (for example, granitic), then a root is formed in such a way that the light rock penetrates and displaces the heavier rock below. The result is a deficiency of mass and a consequent negative anomaly. Sediments in such troughs, either already present or rapidly brought in by deposition, are squeezed up so that when the horizontal compressive forces are relaxed, an island chain rises, along which there is still a large negative anomaly.

In some of the great trenches of the open ocean, and along the continental margins, the situation is somewhat different. Here the relatively thin basalt layer of the oceanic crust is bowed down, and little

sediment is deposited. The negative anomaly is along the axis of the trench and is due primarily to a deficiency of mass, which is attributable to the water column and, to a lesser extent, to the lighter basalt's displacing the underlying, heavier rock (*29*).

Most of the island-arc structures have an associated arc of volcanoes and nonvolcanic islands on the concave side of the trench. In recent years the study of all types of earthquakes, especially deep-focus ones, has revealed that there is a direct connection between these disturbances and the great trenches. At the present time it is thought that many of the trenches are the surface expression of the down-bowed crust intersecting a great, dipping fault plane (Fig. 1). A recent paper by Benioff illustrates the present concept (*30*). In an oceanic fault-trench system, such as the Tonga system, the fault dips downward to the west at about 60 degrees, and earthquakes are known to about 700 kilometers below the surface of the earth. Along the margins of continents the fault plane dips under the continent and is more likely to have a triple structure, with a shallow component to about 70 kilometers, an intermediate component with an average dip of 33 degrees, and then a deep component from 300 to 700 kilometers, with a dip of about 60 degrees. The fact that the earth's crust can build up shear stresses at depths down to 700 kilometers over a long period of time and can then relieve these stresses by slippage along a fault plane, thus causing an earthquake, is taken to mean that the crust is not fluid down to that depth, although it certainly cannot be denied that there are plastic flow and other slow movements.

Within the past few years, another remarkable feature of the trenches has been noted; in many of them, notably the Puerto Rico Trench and the Acapulco Trench off the coast of Mexico, shallow-water sediments, such as sand and silt, containing animal and plant remains have been sampled at the greatest depths. These sediments could have

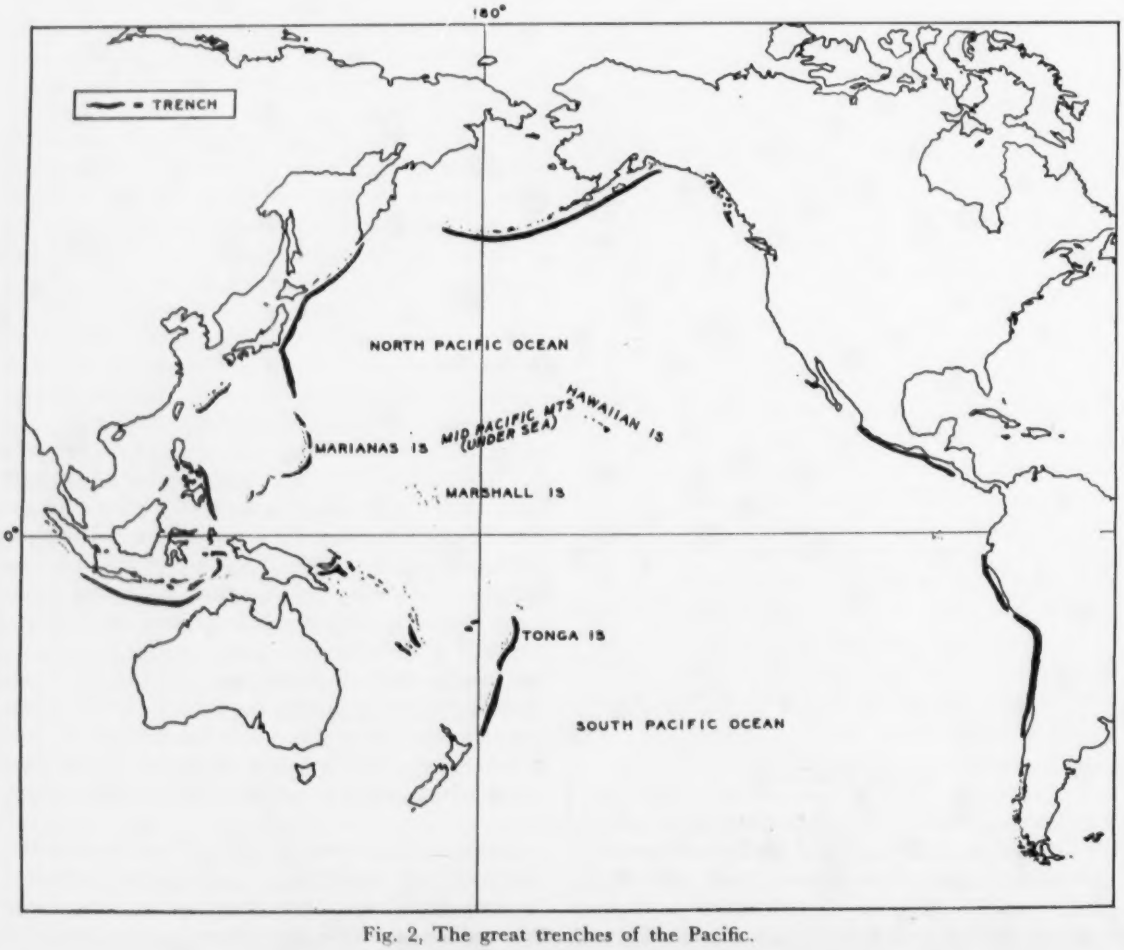

Fig. 2, The great trenches of the Pacific.

come only from adjacent, higher portions of the sea floor and were probably deposited by the density currents previously discussed. The extent of such deposition in the Puerto Rico Trench might be as much as 12 kilometers, and these sediments alone might explain the great gravity anomalies of the region (*27, 31*).

In the Pacific Ocean Basin it is probable that density currents are not as important a factor in deep-sea deposition, owing to the entrapment of the sediments in the marginal trenches and basins which are found around most of the Pacific.

Great Fracture Zones

Geologists who like to study the "big picture" have long been concerned with correlation of great linear structures of the earth's crust. Unfortunately, on land, erosion has taken its toll, and such study has to be confined largely to the "ruins" of a landscape or structure. In the sea, where a structure is not subjected to powerful erosive forces but, more or less, lives forever, there is afforded a chance to determine some of the great deformations and changes through which the earth has passed. Between 1950 and 1953, Menard, using the topographic information from old soundings plus the results of half a dozen expeditions from the Scripps Institution and the Navy Electronics Laboratory, discovered four great parallel fractured zones in the sea floor of the northeastern Pacific (*32*) (Fig. 3). The northernmost zone, extending westward from Cape Mendocino for more than 1400 miles, is notable for a great escarpment which, in places, is as high as 10,500 feet. Subsequent expeditions, generally directed before they set out to positions where it was thought the zones should be, have discovered several other linear fracture zones. South of the Mendocino Escarpment there lies the Murray Fracture Zone, which can be traced almost to the Hawaiian Islands and which, indeed, may transect that structure and continue into the Mid-Pacific Mountains to the west. Farther south, and lying westward along the Revilla Gigedo Islands from Mexico, the Clarion Fracture Zone cuts the sea floor for at least 1700 miles; to the east, it is thought to cross the continent along the lines of the volcanoes of southern Mexico. The last zone to be discovered and the one presently under intensive study is the Clipperton Zone, which has been traced for more than 3300 miles. All of these zones lie almost along straight lines on the earth—great circles—and Menard believes that they, the great San Andreas fault of California, and possibly the faultline of the Hawaiian Islands, were formed as one great integrated fracture system by the plastic deformation of the earth's crust. Little data are presently available on the date of this mighty deformation, but from present evidence we can guess that it might be as old as late Mesozoic or early Tertiary. The mighty force which could cause such a vast deformation of the outer crust must be sought in the interior of the earth. Menard mentions two hypotheses which might explain these great fault zones: a migration of the poles from a position in India to the present position or the slow movements of great convection currents in the plastic material of the earth's mantle underneath the harder surface crust. These great convection currents have been increasingly discussed for the past two decades as possibilities for explaining large-scale phenomena but, for the present, they must be considered hypothetical (*32*).

Seamounts and Mountain Ranges

From the earliest days of exploration it has been realized that the islands of the oceans are mainly the projecting peaks of mountains on the sea floor. Most of the islands in the Central Atlantic are from the great submarine mountain range of the Mid-Atlantic Ridge. In the Pacific, all of the Hawaiian Islands are peaks along the top of a great submarine ridge over 1600 miles long. The Marshall Islands are coral caps on great volcanoes, and spread all over the Pacific are thousands of other seamounts which do not reach the surface. Others, now known by the score, were formerly islands but now have sunk as much as a mile below the sea surface.

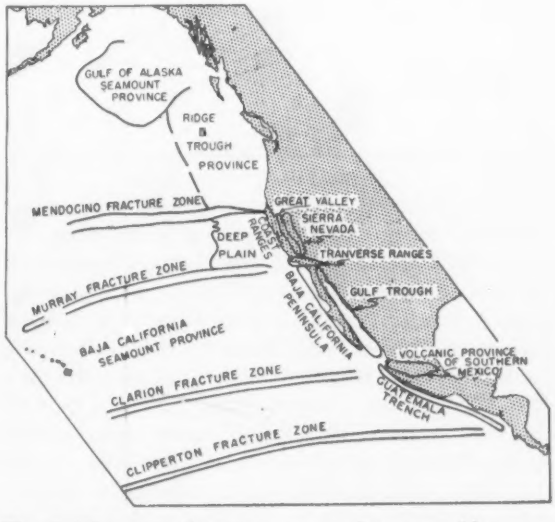

Fig. 3. The great fracture zones and topographic provinces of the northeast Pacific (after Menard, *32*).

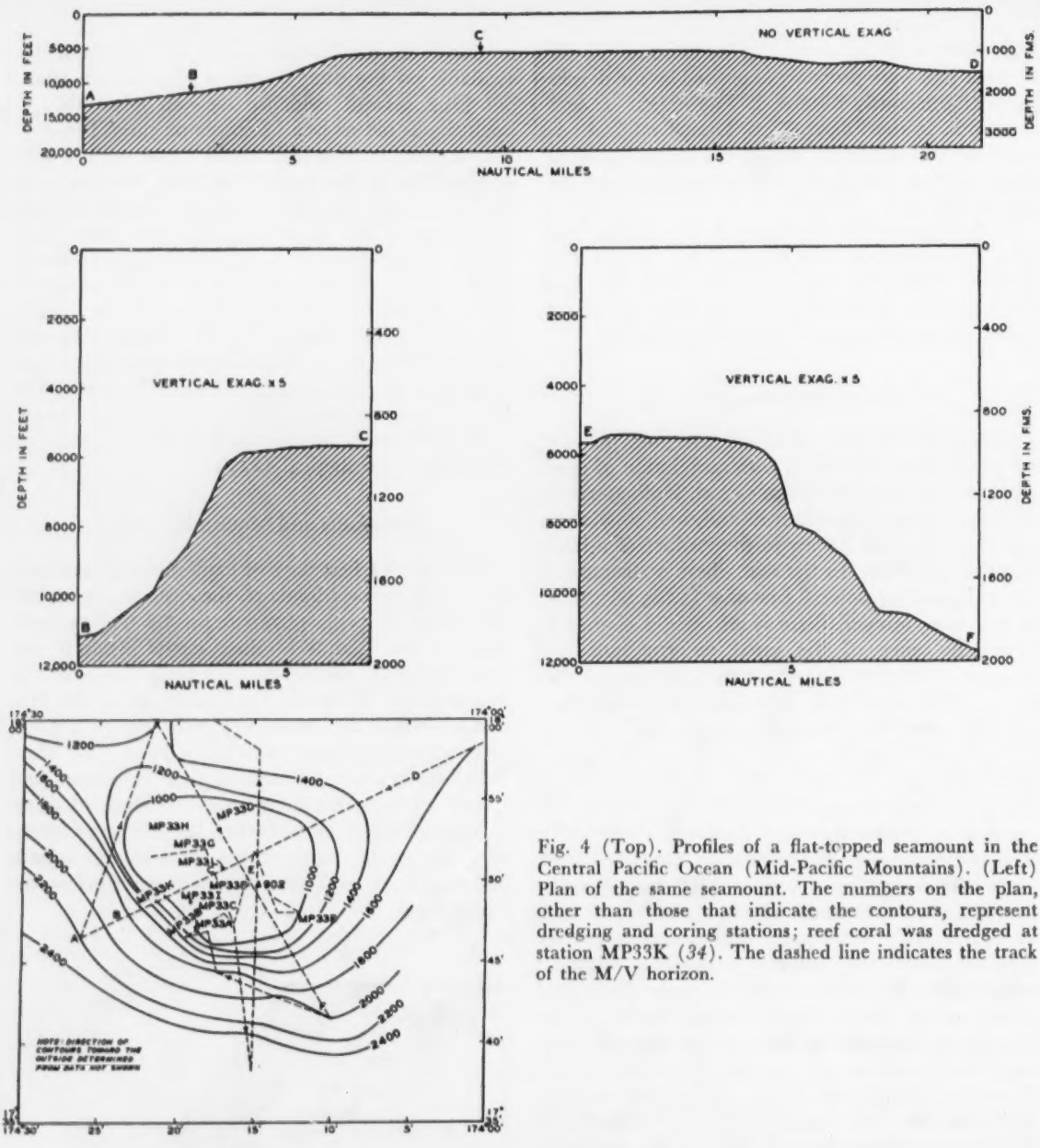

Fig. 4 (Top). Profiles of a flat-topped seamount in the Central Pacific Ocean (Mid-Pacific Mountains). (Left) Plan of the same seamount. The numbers on the plan, other than those that indicate the contours, represent dredging and coring stations; reef coral was dredged at station MP33K (*34*). The dashed line indicates the track of the M/V horizon.

This latter group of seamounts—former islands, now sunk beneath the sea—has been a fascinating problem in marine geology for the past decade. During World War II, Harry Hess of Princeton University, then a Naval Reserve officer, was navigator, and later commanding officer, of the transport *U.S.S. Cape Johnson*. This vessel, as part of the U.S. wartime fleet, made many long voyages in the Central and Western Pacific. Hess, under extremely difficult conditions, maintained his scientific curiosity about the sea floor and studied the records of the echo sounder as they slowly revealed the profile of the sea floor lying under the ship. He noticed, one day, a great symmetrical submarine mountain with an apparent flat top—a top too flat and too big to have been the crater of a submerged volcano. He later crossed 19 more of these features and discovered many more in the records of the U.S. Navy Hydrographic Office. On the basis of the shape and size of the features, he believed that the flat top could have been formed nowhere else than in the wave zone of the sea surface—in short, that these features were ancient, drowned islands! This exciting information was published in 1946 (*33*);

it was realized immediately by Hess and others that some of the seamounts in the Gulf of Alaska were probably former islands, and the necessary additional proof was eagerly sought.

In 1950, the Mid-Pacific Expedition of the Scripps Institution and the Navy Electronics Laboratory, in exploring a vast region of the sea floor west of Hawaii, discovered a continuous submarine mountain range extending from the vicinity of Necker Island, in the Hawaiian group, to the vicinity of Wake Island (Fig. 2). This mountain range towered more than 13,000 feet above the sea floor to the north and south. Many of the topmost peaks of this range had the anomalous flat tops noted by Hess.

After a topographic survey with echo sounders, five of the flat-topped seamounts, ranging in depth from 700 to 1100 fathoms, were sampled for rocks and sediments by dredging and coring (Figs. 4, 5). The following material was recovered from the tops and upper side slopes of these truncated volcanoes: (i) Pebbles, cobbles, and boulders of olivine basalt, many of them rounded, as are similar materials in rivers and on beaches; (ii) phosphatized limestone containing an integrated, shallow-water, reef-coral fauna of the Upper Cretaceous; at one station, reef coral and sandstone were collected in the same dredge haul.

Four of the seven genera of reef coral recovered from the seamounts are living in present-day seas. Reef coral lives only near the surface of the sea. This fact, plus the rounded pebbles, cobbles, and boulders of basalt and the presence of sandstone, plus the general shape of the seamounts, made it possible to draw important conclusions: There is now, in the north central Pacific, a great, undersea mountain range, with peaks now at depths between 500 and 1100 fathoms; this great range lies in an east-west direction and extends from the Hawaiian Islands nearly to Wake Island. This undersea range, named the "Mid-Pacific Mountains," once formed a chain of islands during the Cretaceous—at the time when dinosaurs still roamed the continents.

The projecting peaks of this ancient chain were eroded to flat banks in the Cretaceous seas, and reef corals, probably from the east, found lodgment on and among the erosional debris in the warm tropical surface waters. Growth of this reef-coral fauna progressed far enough to form banks but not far enough to conceal the erosional debris and form an atoll.

For some reason that is not known, probably having to do with isostatic adjustment or subcrustal forces, the whole great undersea range sank and, initially, sank fast enough to kill the reef coral when the coral dropped below its life zone in the upper waters. Subsequently, subsidence of the Mid-Pacific Mountains took place until they reached their present depth, where they remain today as the oldest uneroded mountains known on earth. They are fossil landforms preserved in the depths of the sea, where they are disturbed only by light currents and the slow rain of pelagic material from the waters above (*34*) (Fig. 6).

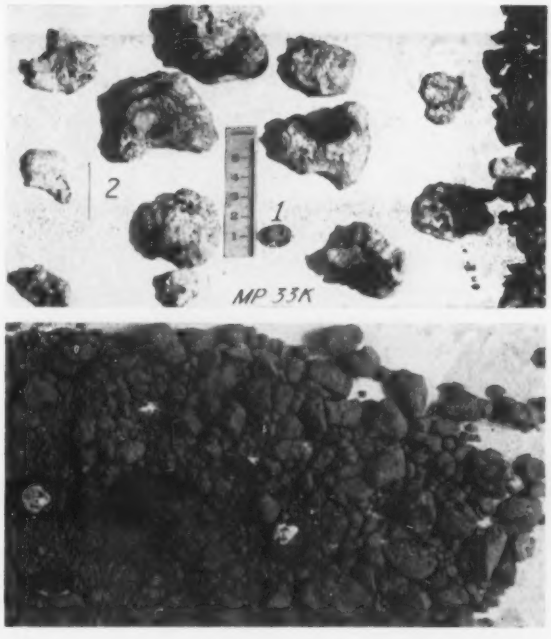

Fig. 5 (Top). Dredge haul from station MP33K (see Fig. 4 for location); almost all the larger fragments are Upper Cretaceous reef coral coated with black manganese oxide; at *1* is a beautifully preserved echinoid of the Upper Cretaceous; at *2* are reef corals. (Bottom) Basaltic gravel and sand mixed with red clay and fossil Foraminifera, from a core taken at 2050 fathoms near the foot of an eroded ancient island (*34*). The numbered pebbles were thin-sectioned.

Coral Atoll Problem

After Charles Darwin returned from his voyage in *H.M.S. Beagle* he formulated and published (1837 and 1842) his ideas on the origin and history of coral atolls. His principal explanation for these great structures is the well-known theory that barrier reefs and atolls develop from the subsidence of islands on which coral has found lodgment as a fringing reef. This "subsidence theory" was widely accepted and was for many years the favored explanation for most coral reefs in the form of atolls and of barrier and fringing reefs. Later in the 19th century the idea was challenged, and several other possible solutions to the problem were presented. In the welter of subsequent controversy, the fact that Darwin had already suggested other possible

Fig. 6. An artist's conception of the Mid-Pacific Mountains as they would appear if the Pacific were drained away, leaving the sunken islands as emerged and truncated volcanic cones. This is a photograph of an oil painting by Chesley Bonestell and is based on part of the bathymetric chart of the Mid-Pacific Mountains (*34*). [Courtesy Chesley Bonestell]

ways in which atolls could form was largely overlooked. Darwin clearly stated how atolls could grow up from submerged banks, with or without subsidence of the foundation. In the third edition (1889) of his book of 1842, he states (*35*): "I may here observe that a bank, either of rock or of hardened sediment, level with the surface of the sea and fringed with living coral, would be immediately converted by subsidence into an atoll without passing, as in the case of a reef fringing the shore of an island, through the intermediate form of a barrier reef. As before remarked, if such a bank lay a few fathoms submerged the simple growth of the coral, without the aid of subsidence, would produce a structure scarcely to be distinguished from a true atoll."

Thus, Darwin anticipated in these auxiliary postulates several other hypotheses for the origin of coral atolls, especially those calling for antecedent platforms.

In 1910 Daly proposed his glacial control theory, which, at first, competed with Darwin's ideas (*36*). Daly discounted subsidence as a major factor in atoll formation and emphasized the planation of platforms during the lowered sea levels of the ice ages, the death of the coral, and its retreat into isolated tropic seas, whence it merged to repopulate the abraded platforms. Although his original ideas have had to be considerably modified and restricted, most geologists admit that glacial control has had important modifying effects on present-day reefs. In 1928, Davis, while defending the subsidence theory, admitted the modifying effects but relegated them largely to the marginal areas, where cold water might have killed the coral during ice ages. We now know from paleontological data

that the warm-water faunas, including coral and Foraminifera, lived through all the ice ages, with probably a mere restriction in living zones toward the equator.

An excellent summary of the reef coral problem to 1949, by Ladd and Tracey, was published in *The Scientific Monthly,* and the reader who is interested in other theories is referred to that paper (*37*).

The evidence on atoll formation in the Pacific Basin accumulated rapidly after World War II. A relatively detailed survey was made of the atolls and flat-topped seamounts in the northern Marshall Islands in connection with the use of the area as an atomic weapons proving ground. A final paper on the geology of Bikini and nearby atolls was published in 1954 by Emery, Tracey, and Ladd and is a classic in the field of atoll studies (*38*). The evidence for subsidence of the sea floor in the central Pacific is almost conclusive.

At Bikini, a hole was bored by oil-well drilling equipment to 2556 feet, where it ended in shallow-water coral debris of the Oligocene or upper Eocene (*38*). At Eniwetok, a hole to 4222 feet ended in olivine basalt underlying Eocene shallow-water sediments and fossil material (*39*). On the flat-topped seamount adjacent to Bikini (Sylvania Guyot), a recent discovery of earliest Eocene fossil Foraminifera in cracks inside manganese-covered volcanic materials gives a date which fits very well with the ages of the sediments in the bore holes (*40*). These datings, plus the geophysical work at Jaluit Atoll and in the Marshall Islands, gives definite proof that the coral atolls of this area are calcareous caps on great volcanic mountains—mountains which were formerly at, or near, the sea surface when the coral began to grow. The evidence from the Mid-Pacific Mountains previously cited was additional proof of great subsidence which extended the probable area to the whole Central Pacific Basin, although the subsidences may be only local or, at most, regional.

An important contribution was made to the coral-atoll problem by Hoffmeister *et al.* and by Hoffmeister and Ladd when they called attention to the geographically wide-spread and quantitatively important presence of pyroclastic material (ash, lapilli, and so on) from some of the Pacific islands (*41*). They pointed out that a volcanic form composed of such material will be quickly eroded to a submerged bank (this has been the case a number of times in recorded history) where coral could find lodgment and, if the seamount subsequently sank, an atoll might be formed.

The flat-topped seamounts of the Mid-Pacific Mountains furnish an example of coral lodgment on a flat platform. If submergence in the area had been slower, the Cretaceous coral would have kept pace with the sinking, would have remained at or near the surface, and would probably have formed an atoll (*34*). The eventual results might well have been similar to the atolls at Bikini and Eniwetok, the latter structure having apparently been formed on two such flat-topped features (*33*).

The coral atoll problem, at least as far as the Central Pacific is concerned, has been solved. These giant coral structures are caps on the tops of submarine volcanoes; these volcanoes are either peaks on submarine mountain ranges or individual peaks, and many of them were apparently planed flat at the sea surface, where the coral began to grow. Later, the coral-capped seamount subsided slowly beneath the surface, and the coral kept pace with the sinking to form the atolls we see today.

The datings of fossil material previously mentioned indicate that the atolls of the Central Pacific area began to grow at the surface in the Late Cretaceous and early Tertiary.

An important problem in connection with the formation of atolls is that of whether the sea floor sank or the ocean level went up. Most marine geologists today think that the sea floor has subsided, but there is a small minority who think that perhaps the ocean volume increased enough to explain most of the relative sinking of the seamounts. If the latter idea is correct, something on the order of a 30 percent increase in the volume of the oceans must have occurred during the last 100 million years.

If we accept the theory of sea-floor subsidence, there remains the problem of whether the whole floor of the central Pacific sank or whether there was a relatively local, or at most a regional, sinking beneath each seamount, group of seamounts, or mountain range. The balance of evidence at this time favors a local-to-regional sinking. Recent studies around the Hawaiian Islands show that this relatively young, and still active, range has imposed a tremendous burden on the earth's crust, and that the crust has been so down-bowed under this weight that elastic side bulges or arches are present on each side of the central ridge (Figs. 7, 8); this is a problem in foundations and mechanics of the earth's crust on a vast scale! It appears that the Hawaiian Islands have undergone some subsidence, with the burden now borne by the crust on a regional basis. This confirms the original findings of Vening Meinesz in the area. It thus appears that a goodly part of the sinking of seamounts and submarine mountains is due to the effect of their great weight on the earth's elastic crust (*42, 43*).

It is felt that the evidence from the central Pa-

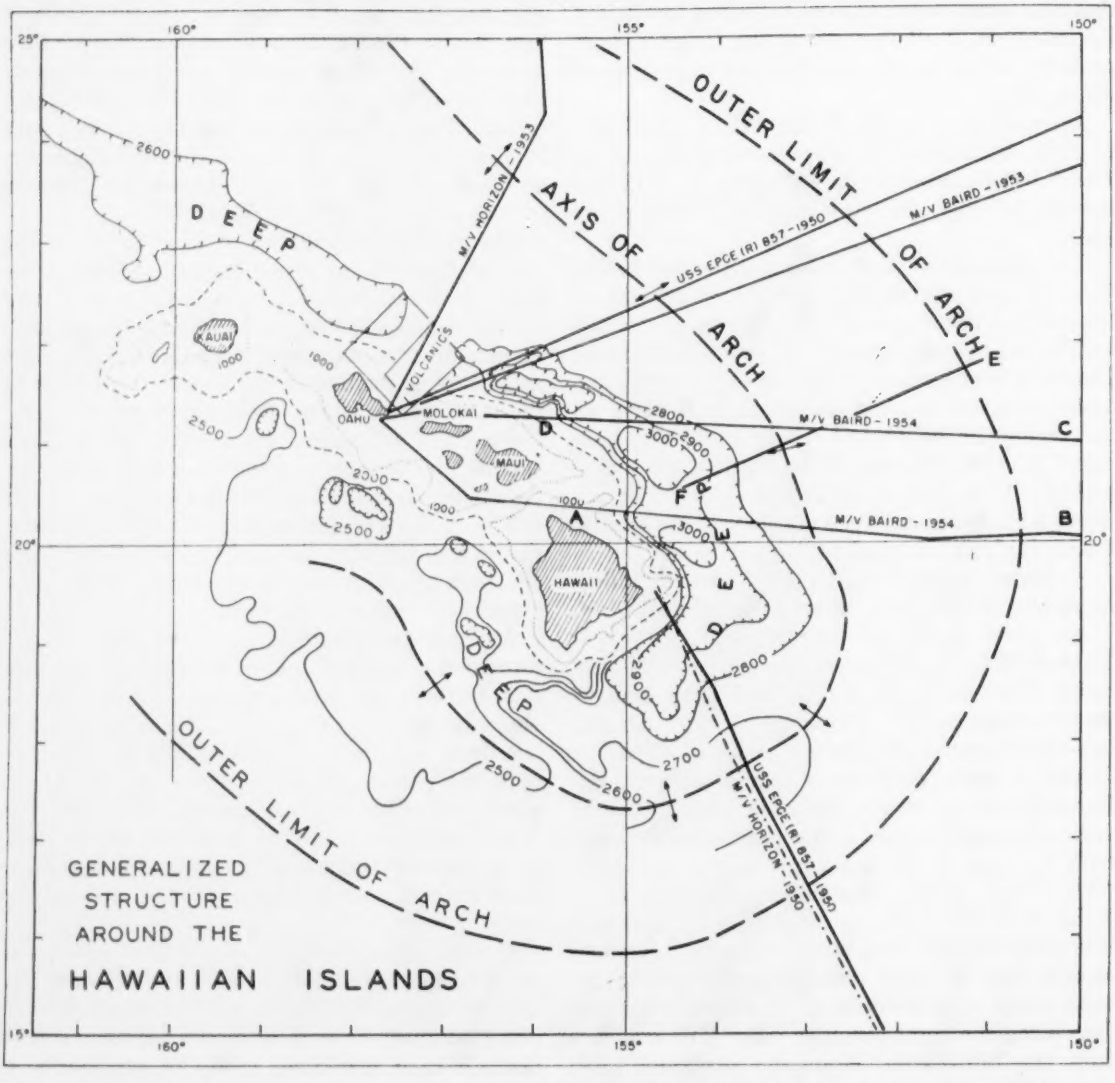

Fig. 7. Generalized structure around the southern end of the Hawaiian Ridge (*43*). The main ridge, with its peaks emergent as islands, lies in a down-bowed area of the earth's crust, surrounded by an elastic up-bulge of the sea floor (the Arch).

cific in the past few years gives strong support to Darwin's original subsidence theory and its auxiliary postulates; these ideas of course have to be modified by the now known ideas in relation to the lowered sea level of the ice ages. Such modern syntheses of coral atoll hypotheses can be found in papers by Kuenen, Stearns, and Tayama (*44, 45*).

Given the favorable ecologic factors for reef-coral growth, including a foundation whose top is within the depth zone of reef growth, a coral reef will grow to the surface regardless of still-stand or submergence (granted slow subsidence or submergence). It is theoretically possible for all of the various kinds of reefs to form with and without submergence. No theory is all-embracing, and attempts to explain all reefs with one theory are doomed to failure. The happy conclusion here is that almost everyone is right at some time and in some places (*45*).

Deep-Sea Stratigraphy

One of the greatest problems in geology is to determine an absolute time scale in years, so that events of the distant past can be properly correlated and a valid history of the earth can be derived. Educated guesses were the best recourse of

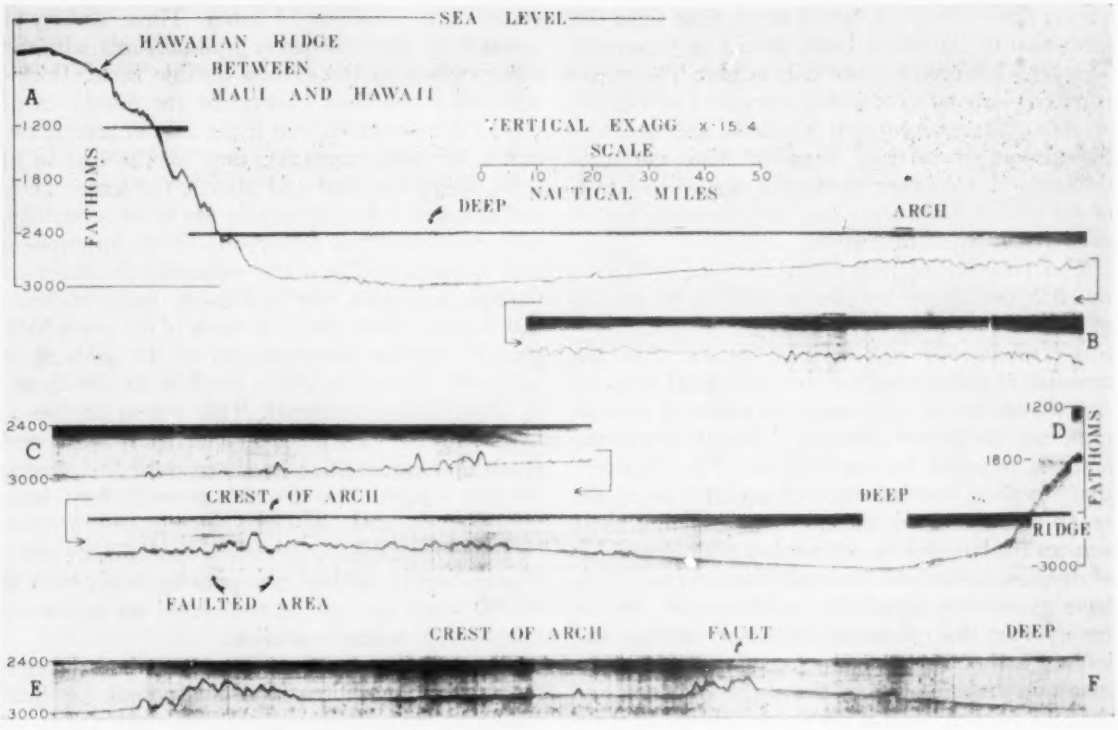

Fig. 8. Echo-sounder records across the Hawaiian Deep and Arch. For location of these lines see Fig. 7 (*43*).

scientists until the discovery of radioactivity in the latter part of the 19th century. Prior to that time, guesses about the earth's age were based on the thickness of sediments, estimates of the annual rates of sedimentation, the amount of salt in the sea, and similar indefinite criteria, which yielded results later shown to be highly inaccurate. The paleontologic record was fairly well established about the time that the first proposals were made concerning the possibility of setting up a time scale based on radioactivity.

The paleontologic record was established by hundreds of geologists and paleontologists over, roughly, a 100-year period. Gradually a picture of the slow evolution of species and changes in faunas emerged from the rocks. This jigsaw puzzle utilized biologic studies as well as the general geologic law of superposition: the strata on the bottom are the oldest. In a given region a columnar section could be established, so that the biologic changes could be seen in one continuous sequence; these sections, when correlated over the world, yielded a picture of biologic evolution, starting from the times when life first existed in forms that could be preserved in the rocks.

Until the discovery of radioactivity, about all that was truly known of the age of the earth (and of the duration and events of life on earth) was that the earth was *probably* extremely ancient. The whole idea of the great age of the earth was challenged in many quarters, including the religious, until the geochemists showed that numbers, based on the rate of radioactive decay of certain minerals, could be placed in the paleontologically-established geologic time scale.

The establishment of a radioactive clock for geologic time has, at the present time, barely started. An excellent and readable summary by Kulp is available in *The Crust of the Earth* (*46*). The main research has been, and probably will continue to be, concerned with the decay of the uranium series, from uranium-238 through ionium (Th^{230}) and radium (Ra^{226}) to lead (Pb^{206}). Within a million years after deposition of a radioactive mineral, an equilibrium is established between the original mineral and the intermediate- and end-products. Inasmuch as the half-lives of the isotopes are known, the length of time that has elapsed since deposition can be established (*46*).

If a place could be found on earth where the deposition of sediments had been continuous throughout geologic time, then a record of important events on earth might be established, especially for the ice ages of the past million years. The best

hope for this section has always been the deep sea, where, theoretically, a record of all time since the formation of the ocean basin should be preserved. This hope has been realized only in part. The piston corer can only take cores of the sea floor to a depth of about 20 meters, which is usually only into the Pleistocene, or ice age, deposits. Also, the total thickness of sediments above the presumed basalt of the earth's outer crust may be anomalously low, as is shown by seismic work.

The presence of radium in deep-sea sediments was first established by Joly in 1908, in his studies of samples obtained by the *Challenger* and *Albatross*; subsequent studies have shown that the amounts of radium and ionium in surficial deep-sea deposits are larger than might be expected because uranium, the parent element, is not present in the amount required for equilibrium. The discovery that uranium was in excess of equilibrium in the ocean waters led researchers to suspect that there was an explanation in connection with deposition of deep-sea sediments. Holland, Volchok, and Kulp have apparently solved this problem with the discovery that the excess deposition of radium and ionium is due to chemical adsorption of these elements on the mineral particles of the sediments and that the phenomenon is involved with the base exchange nature of the sediment particles present (*47*).

Urry and Piggot determined, from the study of deep-sea cores, that radium built up to a maximum below the surface of deep-sea sediments and then decreased in a curve as the investigations went farther below the surface. The explanation for this phenomenon is the fact that radium is at first produced by its parent ionium in excess of the rate at which radium is decaying. Once equilibrium is reached, the radium concentration is controlled by the decay of the ionium. Ionium decreases with depth in a core because there is insufficient uranium to support it; radioactive equilibrium is finally achieved at a depth at which the uranium present is producing as many atoms of ionium as are being lost by the disintegration into radium (*47*).

The uranium-lead time clock is applicable from the formation of the mineral containing uranium to about 10 million years ago. By use of this radioactive series, the age of the earth has been figured to be, at a minimum, 4500 million years (*46*). Another system of time measurement is necessary for the span from 10 million years ago to the present. Two methods have been derived which help fill this span; these are the carbon-14 and ionium methods.

The carbon-14 age determination method was discovered by Willard F. Libby, then at the University of Chicago. He noted that cosmic particles entering the upper atmosphere were known to cause a reaction wherein a nitrogen-14 atom is converted into a carbon-14 atom. These carbon-14 atoms from the atmosphere gradually mix with the other carbon in the carbon dioxide cycle. If this conversion has been continuous for thousands of years (this would be true if the rate of cosmic ray influx has been constant), then all the carbon in living things (animal and plant), the atmosphere, and the waters should contain the same percentage of carbon-14. When removed from the atmosphere and incorporated into the carbonate in water or biologic materials, the carbon-14, being radioactive, begins to decrease at the rate of 0.5 every 5570 years. A precise determination of the amount of carbon-14, therefore, makes possible the age dating of carbonaceous material. This system has revolutionized the dating of archeological sites, and much new information has been published during the past 5 years. Two readable accounts have been published, by Kulp in *The Scientific Monthly* and by Broecker and Kulp in *American Antiquity* (*48*). The carbon-14 method now permits dating back to 40,000 years ago and is considered an important new tool in sediment studies.

The validity of the carbon-14 method depends on certain assumptions regarding cosmic ray flux; therefore, independent checks, or calibrations, of the method were desirable. These have been made, for the recent past, by comparison with tree-ring data and by checking materials of known age within written history. For age dating beyond several thousand years ago, the method has been checked with the ionium radioactive method, and close agreement validates both methods (*47, 48*).

The ionium method of age dating has been recently proved valid by Holland and Kulp, and by Volchock and Kulp at Lamont Geological Observatory (*47*). This method is based on the inequilibrium relationships of radioelements of the uranium-238 series and is applicable to the time span from about 500,000 years ago to the present. This method is peculiarly applicable to the dating of deep-sea sediments.

All of the radioactive methods of dating deep-sea cores depend, in part, on the type and locations of the sediments being cored. Kulp emphasizes that only normal, vertical deposition from waters above a site permit valid determinations; the presence of slumping, sliding, or turbidity current deposition will tend to invalidate the results. Also, the type of sediment should be homogeneous with regard to chemisorption properties, which means that mineral composition and surface area of grains is important; a core in which red clay and *Globigerina* ooze alternated and were mixed would be difficult or impossible to date (*47*).

The biologic remains in deep-sea sediments—

chiefly the species of the protozoan order Foraminifera—can be used for dating by correlation with the known paleontologic record of the continents. The planktonic Foraminifera are particularly useful for this purpose because, during their lifetime, they drifted in the surface waters of all of the oceans; their deposition on the bottom dates the sediment. By this method, sediments from the Upper Cretaceous to the present time have been dated. On and around some of the ancient drowned islands of the western Pacific, pure Eocene sediments about 60 million years old are exposed at the surface (*49*) (Fig. 9).

The Foraminifera have long been noted as having rather restricted life zones, based on the temperature of the surface waters. Considerable work has recently been done in this field at Lamont Geological Observatory and at Scripps Institution of Oceanography (*50*). The study of the Foraminifera at the surface of deep-sea sediments, and at depths in the sediments, yields much valuable information on temperature fluctuations in the surface waters through time.

There are four general ways in which Foraminifera in bottom sediments can be used to study temperature fluctuations in surface waters. The first, and most used, is the alternation of warm- and cold-water species. The second method makes use of the basic assumption that the areal extent of red clay in glacial times was greater, and the extent of *Globigerina* ooze was less, than at present. The third method is examination of the probable rates of production of total fauna and individual species. The fourth method is examination of the species by the oxygen isotope method, wherein the amount of oxygen-18 in the calcium carbonate shells depends on the temperature of the water in which the animals lived (*51*).

All of the above methods are valid. As glacial cold crept out from the poles, its effect would be felt in the restriction of living zones toward the equator and advancement of red clay along the bottom; thus, the second method would be applicable in very high latitudes in depths where *Globigerina* ooze might be deposited if the planktonic Foraminifera lived in the waters above. In middle latitudes, warm-water species would alternate with cold-water species; in some equatorial areas the cold-water species did not encroach, and warm-water species, although restricted, would be present throughout the ice ages.

An interesting combination of the various methods discussed above was recently made by the Lamont group in the study of the probable time of the last great change from the glacial to the postglacial climates (*52*). Carbon-14 studies, a climate curve from a study of the Foraminifera, and paleotemperature studies by the oxygen-18 method all agreed very well and showed that the major change over the North Atlantic and adjacent seas occurred about 11,000 years ago, when the seas warmed up after the last great glaciation.

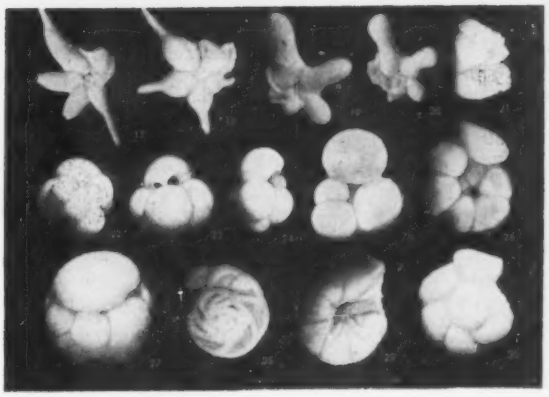

Fig. 9. Fossil planktonic Foraminifera (×25). These individual shells, or tests, were part of an unindurated Eocene sediment cored from the top of one of the Mid-Pacific flat-topped seamounts (*49*).

It is already apparent that investigations of the great weather changes of the ice ages will derive their most valid information from the study of deep-sea cores where, in some places, the sediments have been continuously deposited and undisturbed for the last million years.

Only a small part of the subject of sedimentation in the sea has been discussed in this article. The interested reader can find many summary papers which give, in detail, modern ideas of sedimentation and the constituents of sediments. Modern summaries of deep-sea sediments have been made by Revelle *et al.* and by Arrhenius, for the Pacific, and by Ericson *et al.* for the Atlantic (*53*). The modern team approach to science is very evident in sediment studies. A notable example of the team approach, which must include geologists, biologists, and chemists, is shown by the studies of the American Petroleum Institute Project 51 in the Gulf of Mexico. The purpose of this project was to establish criteria from the study of recent shallow-water marine and estuarine sediments which can be used as an aid in identifying the environments of deposition of ancient sediments. Many of the results of this study for the Texas coast are summarized by Shepard and Moore (*54*), who were successful in establishing the desired criteria, mainly through the study of the coarser constituents of the sediments. Important recent advances have been made in the problem of the origin of oil with the proof that present-day sediments, and those deposited in the recent past, have appreciable amounts

of liquid hydrocarbons (*55*). It appears that marine and nonmarine plant and animal remains deposited with the sediments are the true source of oil, but the problem of the nature of the changes and of the way in which this material collected to form oil pools has not yet been solved (*56*).

The Mississippi delta is an interesting area of sedimentation which has been intensively studied for many years by engineers and geologists. Recent papers by Shepard, Scruton, and Fisk have added much new information on the sediments, environments, and history of the modern delta (*57, 58*). These studies show that the textbook idea of bottomset beds, foreset beds, and topset beds is not entirely applicable to river deltas. In the Gulf of Mexico, in front of the delta, fine sediments with some land plants have a high content of marine fossils, due to relatively slow deposition and high biologic productivity. Over these sediments, and at dips of less than 1 degree, the "foreset beds" are formed of fine sediments with a high content of land-plant detritus, interrupted by rare coarser materials. Over these beds the sediment of the encroaching delta contains abundant land plants but few marine fossils and has many laminated zones of alternating fine and coarse materials. Sea water comes in along the course of the river as far as 125 miles during stages of low water. At this time the silt- and clay-laden fresh water overlies the dense salt water, and a fine, oozy sediment is deposited along the river bottom. This sediment is flushed out during the next high-water stage. Muddy water may then extend into the Gulf for a distance of 65 miles (*59*). The rate of growth of Southwest Pass has been determined from early surveys (1838 and later) and from carbon-14 dates. It appears that the modern "birdfoot" delta began to grow about A.D. 1500 and since then about 27 cubic miles of sediment have accumulated in the delta platform (*58*).

Fig. 10. A diving marine geologist examining a specimen from the sea floor. [Photo by R. F. Dill]

The Free Diver

Within the past 10 years several important new tools and continued development of an older one have allowed the scientist to make a break-through in underwater research and actually look at the sea floor.

The development of the Aqualung by J. Y. Cousteau (*60*) of the French Navy, and Emile Gagnan, a French mining engineer, made the diving scientist a free swimmer along the bottom, who can go in and out of places where the suited, "hard hat" diver cannot go. The essential equipment includes compressed air tanks, to which are attached a regulator which feeds air, on inspiration, into a mouthpiece at ambient pressure; a face plate; a weight belt; and swim fins. In cold water a protective suit is necessary.

The free diver is subject to the same dangers of bends, air embolism, and other maladies as is the suited diver, but if due regard is taken of decompression tables (such as those of the U.S. Navy), and if the diver stays inside the time-depth limits therein prescribed, there is little real danger in diving operations.

In waters of 50 to 60 degrees Fahrenheit, a diver can make about six dives of 15 to 20 minutes each (within the limits given in the decompression tables) during a single day without undue fatigue or danger. Although dives to 200 feet or even more are feasible with expert personnel, most of the working dives are made at depths of less than about 150 feet.

In the field of marine geology, the Aqualung and similar devices have been used to study bottom sediments and sedimentary environments, to collect undisturbed samples, to study minor structures such as ripple marks, and to map underwater geology (*61, 62*) (Fig. 10). An interesting development is the use of diving in the mapping of geologic structure on the sea floor. A field geology team is simply placed on the sea floor, where it does the same things as the dry-land field geologists, in almost the same way (*62*). In the search for rock outcrops the geologists can swim along compass traverses or can be towed just above the bottom by a weighted line from the boat, or can be towed on a special undersea sled with vertical control planes.

Fig. 11 (Left). A photograph of the top of Sylvania Seamount, a flat-topped seamount adjacent to Bikini Atoll. Rippled *Globigerina* ooze is shown among manganese-oxide-coated volcanic rocks at a depth of 720 fathoms. The bottom edge of the picture shows about 6 feet of the bottom [see also (*65*)]. Fig. 12 (Right). A sea-floor photograph taken at 239 fathoms on the east side of Clipperton Island in the east Central Pacific. Large coral fragments from the reefs above are projecting through calcareous debris.

Some interesting things that have been seen off California, not seen on land, are great tar seeps up to 100 feet in diameter and 6 feet high in the center, with an active "mouth" from which a 15-foot-high tar whip extends toward the sea surface; such whips may be 6 inches in diameter at the base and pencil-thin at the distal end. In some areas innumerable natural-gas seeps send curtains of bubbles to the surface; these seeps may come from exposed rocks or through a cover of sand. One realizes that such gas seeps are probably common on land, but their presence cannot be as readily determined.

Deep-Sea Photography

With the use of free-diving equipment there has been a great increase in the use of diver-held cameras, both still and motion-picture, for the recording of underwater observations. The first underwater pictures were taken by Boutan, off the Mediterranean coast of France, in 1893; there then occurred a lapse of over 40 years during which no real attempts were made to photograph the deep-sea floor beyond diver depths. Thus, until 17 years ago, the 70 percent of the earth's surface covered by water remained hidden from the eyes of man!

About 1938, Ewing and his group began to experiment with cameras which could be used to photograph mid-waters and the bottom of the sea beyond diver depths. These assemblies used Robot 35-millimeter cameras and flashbulbs in watertight cases attached to a pole. Early experiments were with free-floating units which were dropped overboard, sank to the bottom, and, after taking pictures, released ballast and returned to the surface. Later models were lowered to the bottom on wire, where a tripping device first struck the bottom and caused a light source to flash during the synchronized opening of the camera shutter (*63*).

This type of camera, informally known as the "Ewing camera," was successfully used in thousands of lowerings by the Columbia University and Woods Hole groups, by Scripps Institution geologists, and by the Sea Floor Studies group at the Navy Electronics Laboratory (*63, 64*). It became immediately evident that the deep-sea camera was of distinct advantage in sea-floor studies in allowing the scientist to examine the microrelief of the sea floor—animal pits, burrows, and trails as well as cobbles, bedrock, boulders, and small hillocks. Sediment types could be studied, and the effects of deep currents on these sediments could be noted. A feature of immediate interest was the fact that ripple marks, long considered evidence of shallow-water deposition by land geologists, were found in the deep sea. Two remarkable photographs taken on the top of Sylvania Seamount in the Marshall Islands area established the fact that the soft, *Globigerina* ooze between the manganese-coated boulders was definitely rippled (*65*) (Fig. 11). Recently Carl J. Shipek of the Navy Electronics Laboratory has found well-defined ripple marks down to a depth of about 6000 feet.

The deep-sea floor was for some time regarded by many biologists as a lifeless area, but photographs have established that the bottom, even here,

is inhabited by its own forms of life, usually varieties of forms found in shallower waters, such as echinoderms, worms, holothurians, sea-pens, and brittle stars. Research workers at the Marine Biological Laboratory of Plymouth, England, have devised a whole program of biological studies for which the camera is used. An example of their findings is an area where as many as 500 brittle stars are found living in a square meter on the ocean floor (*66*). All of these studies tend to confirm a suspicion long held by many geologists that much of the sediment now found incorporated into the rocks of the land was considerably churned, eaten, eliminated, and regurgitated by bottom-living animals.

Development of deep-sea cameras, being a very expensive proposition, has gone along slowly. Work has continued at Lamont and Woods Hole, mainly under Owens, who has taken pictures at depths greater than 3000 fathoms in the Atlantic. Emery, at the University of Southern California, has taken some excellent pictures with the "Benthograph" (*67*) in the Pacific near the continent. Edgerton, of Massachusetts Institute of Technology, has taken the deepest photographs in the Atlantic Ocean (in the Romanche Deep) at a depth of 7500 meters (*68*).

The deepest picture in the Pacific was taken by Shipek off San Diego, at 13,062 feet, in an area showing a flat, red-clay bottom. Excellent shots have been taken around seamounts in the northern Marshall Islands and off Clipperton Island in the east Central Pacific (Fig. 12).

The Bathyscaphe

Man will never be satisfied until he conquers the last, highest elevation on earth, and the deepest depression on earth. Mount Everest has been climbed. The only challenge not yet met, then, is the deepest depth of the oceans. William Beebe and Otis Barton first accepted the challenge of the deeps and descended to about 3000 feet in the Atlantic Ocean, in 1934, in the "bathysphere." Barton, in the "benthoscope," went 4500 feet off California in 1949.

Auguste Piccard, who went into the stratosphere in his balloon, the FNRS-1 (Fonds National de la Recherche Scientifique) began the construction of a manned device to explore the deeps during the late '30's but had to cease operations because of the war. After World War II the plans were resumed and successfully carried through in one of the greatest examples of individual planning, design, and

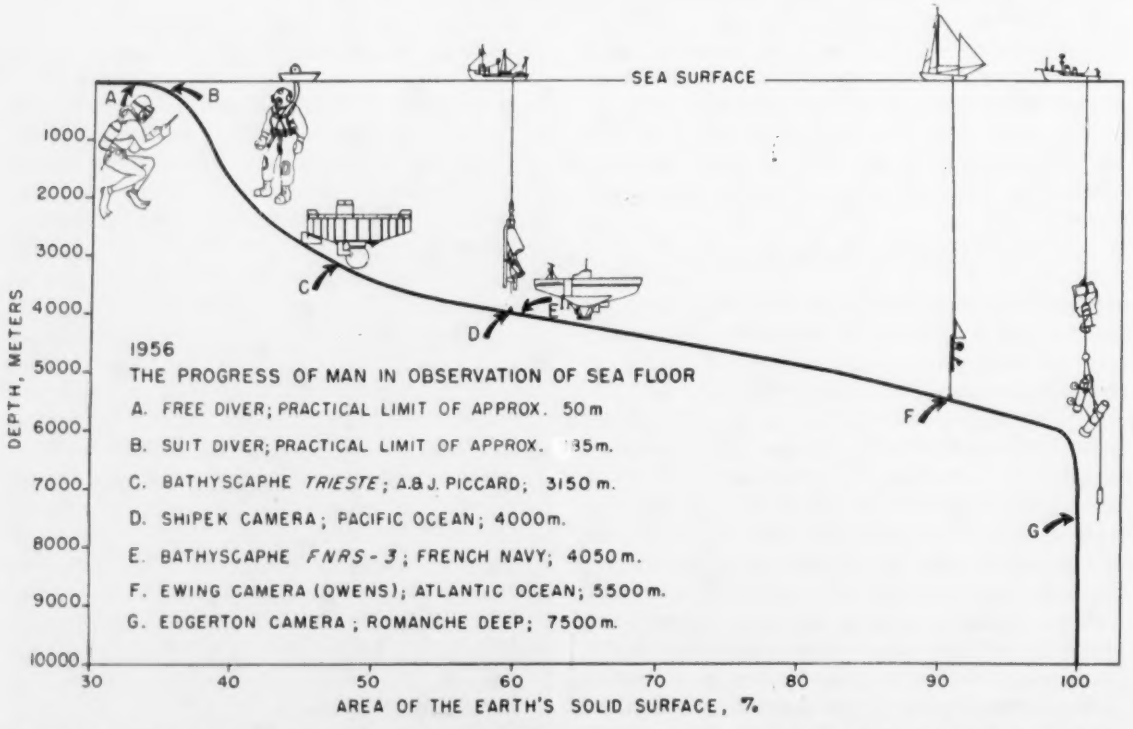

Fig. 13. Hypsographic curve showing the area of the earth's solid surface above any given depth [after Sverdrup, Johnson, and Fleming, *70*]. Along the curve are the present means of directly viewing the sea floor. The percentage of the earth's surface opened up by each method can be determined along the bottom line.

construction in the history of science. In these days of the multimillion (or billion)-dollar-team approach to scientific endeavor, it is refreshing to see a break-through in science effected by so few persons with so little money.

The "bathyscaphe" developed by this group is the underwater analog of the blimp. The two present bathyscaphes are, essentially, hollow steel spheres suspended under thin hulls. The hull of the second bathyscaphe, the *Trieste,* has 12 separated compartments which can be filled with gasoline to provide the lighter-than-water feature; ballast and sea-water flooding control descent and ascent. The 10-ton sphere is 2 meters in inside diameter and has a wall thickness of 9 centimeters, thickened to 15 centimeters near the two ports. Some horizontal maneuverability is made possible by battery-driven twin screws (*68*).

Piccard, with his son Jacques Piccard and Max Cosyns, completed his first bathyscaphe, the FNRS-2, in 1948, and with the assistance of the French Navy had it towed to the vicinity of Dakar for the first test dives. An unmanned dive was made to 1400 meters and a manned dive to 25 meters; after this the tests had to be abandoned because the high seas had damaged the thin, gasoline-filled hull of the vessel.

The French Navy took over the FNRS-2 in 1950 and, with the initial assistance of the Belgians, continued the development of the craft. They redesigned the outside hull and renamed the vessel the FNRS-3. Between 1950 and 1954 the French Navy made about 30 dives to the sea bottom, including the present record dive of 4050 meters. This work has been under the supervision of Georges S. Houot.

In 1952 Piccard, with his son, began to build another bathyscaphe, in Italy, with the help of funds from Italian and Swiss citizens. This project was completely successful, and a first dive was made in August 1953. The new craft was named the *Trieste,* and 15 dives were made by the end of 1954; the deepest dive was to 3150 meters, off Naples. The *Trieste* is designed for descents to 6000 meters but so far has not dived in sufficiently deep waters to break the French record (*69*). At the present time the bathyscaphe is not important as an oceanographic and geologic research tool, but its possibilities are immense.

The progress of man in viewing the sea floor is illustrated in Fig. 13. Man has increased his observation of the earth's solid surface by about 2 to 3 percent by use of the Aqualung and similar free-diving devices; by diving with a suit man can add another 3 percent. The potential use of the bathyscaphe will allow man to view, directly by eye, up to about 60 percent of the earth's solid surface. Finally, with the deep-sea cameras, man can have under observation, by photography, almost all of the remaining 40 percent of the earth. Only the abyssal depths of the great trenches still remain unseen by these methods.

However, it is clearly within engineering feasibility to design both cameras and deep-diving craft which can plumb the greatest depths of the sea. There may well be a race to see whether man will first stand on the moon or conquer the Challenger Deep off the Marianas.

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Scientific Progress and Political Science

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ONE of the most important problems facing political scientists today is the matter of their deficiencies in coping with policy decisions affecting national security in an atomic age. Scientific progress is a remarkable aspect of the culture of our times, otherwise so material and profane. Scientific progress should be universally approved of, at least by intellectuals, despite the extremely menacing nuclear monsters that have been spawned along the way. The political scientist is all in favor of scientific progress in his own field, such as the discovery that, by appropriate samplings of the population, the tastes and opinions of the public can be polled fairly accurately. But the political scientist is concerned much more about the slowness of development in his field than about the possibly dangerous impact of the relatively simple findings he has made thus far. He is acutely aware of his failure to keep pace with the needs which a swiftly developing technology, fed by advances in the natural sciences, has imposed upon society. In a more private recess of his soul the political scientist, like the social scientist generally, worries also because his findings and discoveries do not really register in the way that they do in the natural sciences.

In the natural sciences a significant finding is established as a fact to be reckoned with permanently by all workers in the field to which it pertains, at least until it is definitely superseded by some relevant but different finding. And there is something majestically impersonal about the march of events in the natural sciences. It can almost always be stated with assurance that if one scientist had not made this particular key discovery at some such time, another would certainly have done so within a reasonably short period thereafter. Such a statement does not detract from the credit due the discoverer, whose merit apparently lies less in his special uniqueness of insight than in his position at the van of a movement pressing against the boundaries of knowledge.

The situation is very different in political science, where much excellent work has proved to be writ in water. Political science must, to a large degree, concern itself with the contemporary world, which means with a highly specialized and fortuitous set of circumstances that are bound to change importantly within a short time. That is so even if the political scientist is primarily interested, as he usually is, in the deeper currents of affairs over the long term. The things that are "researchable" and the questions on which his judgment will be sought, if it is sought at all, usually concern the highly specific present. Naturally, work of exceptional quality tends to have some enduring value in any case, partly for the example it sets for younger scholars and also because general insights into man as a political animal are expanded by such work. But these benefits are, as a rule, indirect and marginal relative to the dimensions of the work and to the original value, however temporary, of that work. Also, the author is not likely to be remembered for it, because obviously, in view of the constant vast pressure of new literature, few are going to bother with items that are conspicuously dated.

This point leads to another characteristic that distinguishes political science from the natural sciences, and that is that its product is, and has to be, expository. Political science, like most other social science, is formulated in prose. It has been charged that this is usually bad prose, and it should not be argued that the badness of the prose is necessary. But certainly the few attempts that have

been made to introduce the shorthand language of mathematics into discourse in political science have seemed forced, perverse, and usually ludicrous. The exception, of course, is that of statistical studies, in which for the moment it is found convenient to regard human beings as the strictly identical units which, in all other contexts, political scientists are at special pains to point out they are not. But most of the things regarded as worth communicating require words for their communication, often very many words. The ideas developed often differ from the banal or obvious only in the special nuances applied, which seem meaningful and sometimes even important.

The fact that political science is disseminated only through the use of large quantities of words accounts for a good many idiosyncracies in the field that natural scientists find bewildering. There does not exist in the field a tidy system of inventory for ideas, such as would make for an orderly building of new knowledge upon old, and a considerable price is paid in lost or wasted motion for this untidiness. Another large and unfortunate result of the wordiness of political science is the fragmentation of the field into divisions that may have very little contact with each other. Keeping up with the literature in one's field can at best be done only imperfectly, and even then only if one delimits one's field quite narrowly. This is especially true of those who are, or try to be, productive scholars. The fragmentation cuts through whatever theoretical structure exists in the field. It is not correct to say that there is no theory in political science; there is a measure of empirically based theory in each of the several branches of the discipline. What is true is that there is no body of theory common to the whole, from which the several specializations make their departure. What is generally called "political theory" is usually only a history of distinctive personal philosophies about political systems.

Critic of Public Policy

Mention must also be made of the special kind of split-personality disorder to which almost all political scientists are heir. The political scientist has schooled himself to have a fairly austere conception of the proper scope and methods of research in his field. But he cannot escape, and usually does not want to escape, that aspect of his discipline which requires him to be a critic of public policy where that policy impinges on his specialty. In this respect his position is very different from that of the natural scientist, who, when he criticizes policy, does so only as a citizen and not as a specialist in a field where policy decisions are intrinsic to his subject matter.

It is a simple fact that some of the most baffling and most critically important issues requiring policy decisions, especially on the national or international level, are not in any direct way "researchable." Problems may be formulated and investigated which are in some way relevant to the basic policy decisions, but often they are so only tangentially. Policy decisions involve predictions about the future and must often take account implicitly of a wide range of contingencies. The political scientist often can, as a result of accumulated research in his field, point out that some contingencies are much more probable than others or that certain popular proposals have a demonstrably poor chance of success. These can be important contributions, and it is a pity that such analysis is not used more regularly when it is available. When it is so used, systematically and carefully, it becomes a kind of research in itself. The now familiar term *operations research,* broadly conceived, would encompass such an activity.

Even so, on the major issues there usually remains a broad area for the exercise of something other than research talent, and the political scientist is not free to abandon this area. Insofar as the policy decision in question impinges on a field in which he has a special competence, he may justly hold that his intuitions are likely to be sounder than those of individuals not similarly endowed with information and experience. Yet, fundamentally, his opinion concerning policy has to be accepted or rejected on the basis of someone else's intuitions about his abilities, because he can offer nothing that he himself would regard as a satisfactory proof of the correctness of his position.

It is true that "experts often disagree," and nowhere are they likely to disagree more than in political science. But in the process of disagreeing, scientifically trained experts are likely to expose sharply to each other and to the world not only the content and the boundaries of the knowledge they consider relevant but also the character of the logic by which they test relevance, meet each other's objections, and attempt to erect a connective tissue between known facts and the question to be decided. The fact is, also, that the experts generally disagree a good deal less than is commonly supposed and that they have much more than average immunity to some of the lay notions on the subject at hand that may be current.

It should be remembered that the nature of political science is determined by a subject matter which is fundamentally different from the subject matter of the natural sciences in several crucial

respects, especially in the transitoriness of the patterns which it studies. It is possible to establish certain universal propositions or "laws" in politics, but they have a tendency to be banal and uninteresting in direct proportion to the degree to which they are universal. Political science is no doubt more disorganized than is necessary and, in its diverse departments, less precise in method than is desirable. But there will never be and there never should be anything comparable to a "Gödel's proof" in political science. The field is fated to remain wordy and therefore fragmented, and it will always tend to be oriented around current policy problems. Within those limitations it will produce much useful and even valuable work. In any case, there should be less concern with the intrinsic value of the product than with the likelihood that policy-makers will pay little or no attention to it.

Politico-Military Problems

All the foregoing discussion has reference to characteristics, disabilities, or, perhaps, limitations which are inseparable from the nature of political science. But a weakness exists which is not at all necessary and which demands a remedy. It is a weakness that is pervasive in American intellectual life. There is, in this country, no tradition of intellectual concern with that increasingly wide border area where military problems meet political ones. Political science has a greater obligation in this respect than has any other single discipline. Few scholars consider it their primary business to inquire about the effects that current and projected military developments must have upon politics, and vice versa.

This particular poverty in the intellectual life of the country is bound to be reflected in the world of affairs. Granted that the military approach to strategic problems needs to be extended and leavened by the relevant insights of the statesman, such insights are likely to be undeveloped among those real-life civilians with whom the military actually have to deal. There has been much advocacy of closer communion between politicians and soldiers in matters relating to foreign policy. This closer communion, unquestionably desirable, has been much less often urged on the ground that civilians might have a beneficial influence upon military policy—a fact which reflects an almost universal consensus, presumably erroneous, that military affairs are inaccessible to the layman in a way different from that in which foreign affairs are. The problem is not simply one of achieving closer communion between two groups of men of markedly different training and orientation. It is, rather, that of developing a real competence on each side to penetrate and comprehend the issues with which the other side is currently seized.

The National Security Council is a monument to an aspiration, and the aspiration is undeniably sound. But whether any real enrichment of strategic thinking has proceeded from it is another question. Naturally, where the deliberations and conclusions of an organization are kept too highly classified, one cannot be sure, but it seems clear from evidence available to the public that the National Security Council works much better as a medium by which the military can impress their views on the civilians than the reverse—always excepting the matter of imposing budget ceilings on military expenditures, where arbitrariness generally rules. There cannot be a real enrichment of strategic thinking unless and until considerable numbers of scholars in germane fields begin to concern themselves with the relevant issues.

There are a number of reasons why the contribution of political scientists could be crucial. Among these reasons is the fact that political scientists, especially that group of them who specialize in international affairs, are concerned with the *context* of military operations in a way that the military themselves are not. The military officer is forced by the heavy professional demands of his craft to be preoccupied with tactical, as against strategic, matters, and to the relatively small degree that he concerns himself with the latter, his interpretation of strategy is likely to be a restricted one. Clausewitz, himself a general, pointed out 125 years ago that the object of a war, which is always political and therefore appropriately determined by the politicians, must govern the whole conduct of that war; but this idea has never really been absorbed and digested by the military profession. To the military, the means available, rather than the object, are what determine the character of a war, and they have usually resisted any "interference" from their civilian chiefs with respect to their choice of means.

In the two world wars, the conflict between these two points of view was not particularly obvious. But the Korean war uncovered a deep and pervasive confusion on the matter of ends and means. The politicians restrained the soldiers' use of means because they spontaneously recognized that the true objects of American intervention required such restraints. On the other hand, largely because of the novelty of the situation, the political leaders were so inept at formulating and explicating those objectives that they made basic and even elementary errors of direction—above all, the error of arrest-

ing their military pressure at the first moment that the Communists showed an interest in negotiations. The fact that the negotiations then dragged on for 2 years and resulted in a less-than-palatable truce is something that, because of the bitter distaste it left among the American people, has deeply influenced two Presidential elections.

Americans do not understand a kind of war in which relatively heavy sacrifices are made, yet in which they appear to be committed to something less than a clear victory. Yet "limited" or "peripheral" wars are by all odds the kind most likely to engage us within the next decade or two if we become involved in military actions at all. Noninvolvement may mean surrender of important positions, and certainly the only other alternative, all-out thermonuclear war, is an infinitely more grim and forbidding prospect than any kind of local war. There are good grounds for the common assumption that the former can be avoided—provided that certain elementary precautions not commonly discussed are taken, such as providing for the greater security of the Strategic Air Command. But the posture that deters the enemy from all-out attack does little, if anything, to deter him from making peripheral challenges.

One of the most critical changes wrought by the atomic bomb is almost universally overlooked—and at great peril. The extent and character of military capabilities for *any* future crisis tend to be predetermined by peacetime preparations made long before the event. That is a new situation for a nation accustomed to expanding and reshaping military power when the crisis is extant. The "point of no return" in air-power build-up is the point at which commitment occurs to an air combat capability that rests exclusively on nuclear weapons. What is less obvious is that this popular phrase merely dramatizes a crisis of decision that pervades our entire military structure. And the decisions *now* with respect to military structure will inevitably affect gravely our diplomatic freedom of maneuver in the future.

Decisions have been made and are being made now which will determine whether limited wars can be pursued at all and, if so, under what circumstances and with what constraints. The manner in which the character of any *total* war of the future is being predetermined by current preparations is even more striking, though less interesting from a political point of view, both because it is less likely and also because it is potentially annihilative.

It is obvious, however, that the "massive retaliation" threat is becoming rapidly and sharply less significant, even as an implicit factor in our foreign policy situation. As the Soviet retaliatory air capability continues to grow, the conditions under which we can hint at a possible use of our strategic air force against the U.S.S.R. become vastly more circumscribed. It is likely that it will finally be confined to use *only* against the threat of a direct strategic air attack upon this country, which means that it will cease to be of much significance for a host of lesser contingencies. Yet there is no evidence that there has been any fundamental reorientation of politico-military outlook on the world since the days when America enjoyed undisputed monopoly of the atomic bomb.

Inhibiting Factors

Clearly, these are great problems on which political scientists could have much of value to say, if more of them could interest themselves. But there are several inhibiting factors. The first and most obvious is the matter of security. Training in scholarship and research induces people to seek the boundaries of human knowledge but not the boundaries between those who know and those who do not know. Those who are privy to "classified" information know that, for the formulation and evaluation of national policy, the information in the public domain is so immeasurably greater in volume and significance than what is kept secret that the latter may well be ignored except for quite special problems. But the scholar, who cannot see both sides, may find that point of view difficult to accept, or even incredible. Why so much concern about secrets if the things kept hidden are marginal rather than fundamental in importance? The answer is that, in most instances, the secrets are of relevance to technicians and not to political policy specialists. To be sure, some things of rather grave importance have for a time been kept secret. An outstanding and exceptional example is that of the fallout menace, the existence of which was kept secret for about a year. How can the outsider know how exceptional such a case is? Nevertheless, secrecy is much less important than other factors.

A second inhibiting factor is that the esoteric nature of the military art is commonly exaggerated. Naturally, one does not learn how to be a general by reading books. But no general becomes really outstanding without absorbing a kind of knowledge available in books—and there is nothing to keep civilians from reading the same books. In other words, one can learn from books what is *consequential* (the strategic as distinct from the tactical) about the military art, though very few people attempt to do so.

A third factor in this context is that technologi-

cal change is rampant everywhere in society but nowhere more so than in the military art. With respect to problems central to his profession, the military man himself tends to develop an inferiority complex toward the scientist and the engineer, though he has good defenses against letting his attitude of deference spread. Nevertheless, he has to follow the scientists and technicians in some comprehension of a lore unknown to Mahan or Douhet. The civilian who wants to comprehend the military problems of our time has to do likewise. There is, however, among intellectuals in our civilization, a deep and sharp division between those who know and those who do not know as much about physics as can be learned in a good high-school course; political scientists, presumably, are generally among the latter. Yet, when one considers how, in little more than a generation, the sister field of economics has become populated with young scholars who can discourse easily, and often purposefully, in mathematical terms, there is some hope that political scientists can be induced to do likewise.

Finally—though this does not exhaust the list of relevant factors—there is the factor that tradition determines, to some degree, scope and method in political science. At least to an outside observer, research in the natural sciences seems to be directed by something comparable to free association. The discovery of one fact induces scientists to seek to discover associated facts, and in the process they seem not to be worried about the respectability of the direction in which they are moving. Perhaps those inside the process who are sensitive to such matters are more aware of the existence, even in the natural sciences, of social attitudes favoring or discouraging particular lines of research. No doubt there are fads in research, even in physics, though the existence of such fads is probably less important than is the question of how rapidly they wax and decay. In political science the favored fixations tend to be too enduring even to be called fads, often lasting for a generation or more.

One of the most enduring attitudes of all has been that which exempts the study of war itself from a field in which scholars are intensely (and quite properly) concerned with the matters that tend to produce or to prevent war. The factors already listed are no doubt partly responsible, but there is also some redolence of an attitude that was much more prominent during the interwar period than it is now—namely, that the preoccupation with matters military is somehow immoral in a scholar, or at least not wholly respectable. In the 1920's and 1930's one was expected, instead, to be interested in the finer points of the League of Nations Covenant, which was designed to prevent war. And although that attitude has itself largely disintegrated, its consequences linger on. The military profession is often charged with being unduly staid, but it cannot begin to compete in that respect with the curriculum designers in American colleges.

Neither an indictment nor a justification of political science is called for, but rather an explanation of some of its peculiarities of scope and method. In this, it is necessary to distinguish between characteristics which are intrinsic and deficiencies which are remediable. In the latter respect, the failure of political science to cope with the many political problems associated with the nature of modern war, especially in its more novel aspects, should be emphasized. And the H-bomb does raise some oppressively important issues.

Course Requirements for Future Science Teachers

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EVERYBODY wants well-prepared science teachers in the schools, especially when we are aware that such teachers are in short supply. But what *is* a "well-prepared" science teacher? An attempt to explore this question seems especially timely when many liberal arts colleges are planning new programs for teacher training and numerous special programs for science teachers are being created.

No one can know everything, even within the sciences. Inevitably some realistic limitations must be set, and choices must be made in terms of what knowledge is most useful for the particular functions to be carried out. Certainly extensive and continuous study in the varied sciences is necessary, but an ideal program of study would require more than the total time of 4 years in college. Therefore let us restrict our concern to the most desirable program of studies for a beginning science teacher who has had 4 years of collegiate study.

We might expect that the existing certification requirements of the several states would provide examples for discussion. However, most of the certification requirements are pathetically vague about the specific subjects which a prospective science teacher should command (*1*). In an effort to rectify this state of affairs, deliberate efforts are being made to include scientists as members of, or as advisers to, certification boards. To provide such advice in a constructive manner, some pattern of preparatory studies should be generally accepted.

How Much Is Enough?

The Cooperative Committee of the American Association for the Advancement of Science in 1946 published strong recommendations which have yet to be widely made known and accepted (*2*). These were based on a realistic appraisal of the science teachers' responsibilities in the schools. Half of the secondary schools enroll less than 200 pupils. This means that the total teaching staff in half of the high schools is not likely to exceed ten. Also, half of the pupils attend high schools which enroll less than 400 pupils among three or four grades (grades 9 through 12 or 10 through 12). In such schools the instructional staff may total 16 to, possibly, 20. These teachers are responsible for *all* the instruction offered the children. It is no surprise therefore to find that in many schools those teaching science are responsible for three to five different subjects each day and that often these classes are in two or more areas of study (science and mathematics, for example).

Especially disconcerting is the discovery that a considerable number of teachers, even in fairly large schools (*3*), offer only one or two classes per day in the field of science and have their additional time assigned to classes in other subject areas. This can be rectified by wiser administrative organization, resulting in more effective utilization of the time of the better prepared teachers.

The AAAS Cooperative Committee made five recommendations, all worth repeating. "(i) A policy of certification in closely related subjects within the broad area of the sciences and mathematics should be established and put into practice. (ii) Approximately one-half of the prospective teacher's 4-year college program should be devoted to courses in the sciences (including mathematics). (iii) Certificates to teach general science at the seventh-, eighth-, or ninth-grade level should be granted on the basis of a broad preparation, including college courses in all subjects concerned in general science. (iv) Colleges and certification authorities should work toward a 5-year program for the preparation of high-school teachers; and (v) Curriculum improvements in the small high school

should go hand in hand with improvement in teacher preparation."

In Appendix II to *Manpower for Research,* volume 4 of the Steelman Report (*4*), this AAAS committee "further recommended [that] a *basic program* consisting of 6 to 10 semester hours in each of the beginning courses in biology, chemistry, mathematics and physics be required," and suggested that the following distributions be considered for certification in desired areas: "(i) additional courses permitting the student to complete a total of 18 semester hours each in three subject fields; (ii) additional courses permitting the student to complete a total of 24 semester hours each in two subject fields; or (iii) additional courses permitting the student to complete a total of 24 semester hours in one field, 18 semester hours in a second field, and 6 semester hours in geology and astronomy, thus preparing for certification in three areas, one of which is general science." Had these thoughtful recommendations been widely accepted, even with some modifications, much of the current argument and uneasiness would have been avoided.

How Much of What?

But still there is the question of what courses should be included in these time allocations. When inevitable choices must be made among many courses, some courses must be more desirable than others for future teachers. At least two criteria will help in making such choices. First, the prospective science teacher should have introductory study in the several major scientific areas; second, on the basis of this introduction, some specific fields can be developed more easily than others through independent reading.

Let me adopt the AAAS committee's recommendations of year-long foundation courses with appropriate laboratory work in biology, chemistry, mathematics, and physics. These total, on the basis of 8 semester hours per course, 32 semester hours, or half of the total time available. This foundation program is a *sine qua non* for any prospective science teacher, irrespective of his special interests.

Then there is a second level of highly desirable courses which can be recommended strongly for all science teachers. These, considered as half-year courses, are atomic physics, organic chemistry, vertebrate physiology, integral calculus, geology, and astronomy. These six half-courses would probably account for an additional 24 semester hours, for a total of 56. Yet of nearly equal importance would be half-year courses in electronics, quantitative analysis, plant physiology, and the foundations of algebra and geometry (the mathematics taught in the schools). These desirable courses would add 16 semester hours for a total of 72, but no student should invest that much of a 4-year college program in the subject field. Clearly some deletions or choice must be made from among the second and third groups.

But before we consider deletions or preferred groupings, some justification should be offered for the particular courses cited. Biology teachers report that vertebrate physiology is the keystone of their preparation for teaching. Plant physiology is an equally desirable introduction to the botanical world.

Organic chemistry is central both in modern chemistry and in biology; already introductory sections on organic chemistry are appearing in secondary-school chemistry textbooks. Quantitative analysis introduces the teacher to careful and specific techniques which should be especially valuable in work with students of promising scientific ability.

At least some understanding of the nature and power of the calculus is necessary, not only to the mathematician, but also to the science teacher who wishes to point his students toward the niceties of mathematical analysis. But a close analysis of the assumptions and procedures involved in algebra and geometry seems more desirable for the beginning teacher than does an extensive study of the calculus. A clearer understanding of these components of mathematics should aid the science teacher in tying his instruction in science to that in mathematics—a consummation devoutly to be wished.

Atomic and nuclear physics—the newest frontier, which makes the headlines frequently—must be understood at least in a qualitative manner by the prospective teacher of any science class. Electronics is suggested in preference to any of the other subdivisions of physics, because from it come radio, "hi-fi," television, and electronic computing machines—major components of the world in which children now live and in which they will work.

Particularly noticeable by their absence in our list are some courses of considerable importance to the future science teacher. We have omitted, for example, all courses on the history and philosophy of science, an introduction to research, or the role of technology in modern society. At least some awareness of these areas can be attained through independent reading; also, some aspects of them may appear in the courses recommended. But also lacking is what is known as a "good strong major" in one science.

If, however, we examine what is commonly offered as a 4-year major in one science, designed for the future graduate student and practitioner in that field, we have some difficulties in rational-

izing many of the courses with the actualities of secondary-school teaching. Certainly some knowledge of physical chemistry would be desirable, but how much and on what aspects? Special study of electricity and magnetism, or of optics, would be helpful, but operating skill in quantum mechanics is hardly necessary. Genetics, cytology, and biochemistry are desirable but might be delayed to a fifth year or summer school.

Two Patterns

The specific course recommendations appear in Table 1. For "well-trained beginning science teachers" the four full-year basic courses are mandatory as a start. Some variations and omissions among the "highly recommended courses" can be tolerated, but these must be made on a realistic basis. Two patterns of specialization seem reasonable: biology-general science and physics-chemistry-mathematics. Yet one must be careful not to create a biology major so narrowly informed that he is incapable of handling properly the simple components of the physical sciences that appear in general science. Highly specialized programs in physics *or* chemistry are also to be avoided, both because these two sciences are continually moving closer together and because the teacher is likely to be responsible for both areas.

With unhappiness we have encountered schools desiring teachers whose classes would be in biology and mathematics (algebra and geometry). This is an incompatible combination, since teachers interested in one of these fields are rarely interested in the other. Rather than attempt to prepare teachers for all possible subject combinations, we must encourage school administrators to be more realistic in their assignments of teachers. If biology-general science and physics-chemistry-mathematics are to be teaching specializations, certain patterns of courses beyond the basics are most desirable. The biology-general science major should include organic chemistry, which is essential to an understanding of modern biology. Atomic physics would also be helpful, for radioisotopes are playing an increasingly important role in biological investigations. Some instruction in geology and astronomy should be included. Geology is important for considerations of paleontology and evolution, while astronomy involves atomic and nuclear physics and the "big questions" of cosmogony. These four courses, plus the four basics, would total 48 semester hours and still allow time for three half-courses or more in advanced biology.

For the physics-chemistry-mathematics major, in addition to the four basics, certainly atomic physics, electronics, organic chemistry, and quantitative analysis would be essential. Integral calculus and a deeper study of algebra and geometry would also be needed. These courses, plus the basics, would total 56 semester hours and would leave competition between physical chemistry, geology, or astronomy. If necessary, these courses could be postponed for summer school or on-the-job study. The choice of courses for a "most desirable" program is a difficult one, but it can be approached realistically in terms of the teacher's responsibilities. The proposals made here are not unique; they are already followed in various colleges and several states.

Table 1. Subject-matter courses for a prospective science teacher studying in a 4-year college.

Subject	Basics, 1 year of each required	Highly recommended semester courses	Desirable
Biology	Introductory*	Vertebrate physiology*, plant physiology*	Genetics*, ecology*, cytology*, histology*, biochemistry
Chemistry	General inorganic* (qual. lab.)*	Organic*, quantitative*	Physical*
Mathematics	Analytic geometry and differential calculus	Integral calculus, algebra and geometry	Calculus
Physics	Introductory*	Atomic*	Electronics*
Other		Geology*, astronomy*, meteorology*	History and philosophy of science

* Laboratory essential.

Two Major Criticisms

Two major criticisms will be aimed at these proposals. First, they do not provide for a "good solid major" in one of the sciences; the student will have a smattering of knowledge in many areas and not much in any one. Quite true, but what is the purpose of the "good solid major," and what are the actual responsibilities of secondary-school science teachers? What inherent reason is there for providing a teacher with the advanced technical (vocational?) preparation required for immediate employment or true graduate study in a particular field among the sciences? Already those with a strong but narrow major are too attractive to industry and the Government.

Perhaps it is permissible to inquire: How appro-

priate is the "good solid major" for a secondary-school science teacher? With teachers usually working in a variety of subject areas and attempting to develop the diversified and timely interests of relatively immature pupils, the narrowly trained "specialist" is often faced with questions on subjects on which he is no better informed than are his pupils. All too commonly the physics major applying for admission for the fifth-year master-of-arts-in-teaching program at Harvard presents, as "spread," a considerable background in mathematics and 1 year of general chemistry. Completely absent are courses in biology, geology, and astronomy. Similarly, the chemistry major presents, as spread, only introductory physics and has the same deficiencies. However, the biology majors seem to have the narrowest programs, often not even including organic chemistry, let alone any mathematics or physics. Some colleges graduate students with majors in zoology or botany who have had no study in the other major component of biology; they cannot even teach biology! Put bluntly, the often cited subject-matter deficiencies of many science teachers may have resulted from narrowly designed programs of collegiate study.

The second criticism is that the original AAAS recommendations of at least 60 semester hours in science (including mathematics) is unrealistic and rules out a "liberal education." This criticism requires some close examination. The typical college major in science already takes about this many hours in and around his major. For example, 4 or more years of chemistry, at least 1 year of physics, and 2 years of mathematics is a minimal major program in chemistry. Four or more years in biology, 1 year each in physics and mathematics, and 2 years in chemistry (including organic) are desirable for a biology major. Therefore, the proposal of 60 semester hours, or eight 1-year courses, is hardly a novelty.

Some will argue that all major programs in the sciences are too narrow. This may be correct but does not seem highly pertinent in view of realities. Others may claim that a student who takes this program plus the education courses required for state certification will not have any "liberalizing" electives. This is in error. No state requires, for certification, more than 24 semester hours of professional work in education, including practice teaching. This is equivalent to six half-courses, or three-fourths of 1 year of study. Furthermore, the basic education courses strongly overlap general areas in the humanities and social sciences. Educational psychology is not a far cry from general psychology. Educational philosophy or history deals with the educational significance of great philosophic ideas. The course in foundations of education generally involves modern sociology and the role of the school as a social institution in developing existing social ideas and mores. But even if the future teacher invests six half-courses in prevocational (educational) preparation, he has an equal number of half-courses available to meet general education requirements, or as electives. Granted, the fit is tight; we must be willing to trade some compromises among science courses for some among the humanities and social sciences.

Summary

In summary, the responsibilities assigned science teachers require that they have working knowledge and manual skill in several sciences. To prepare future science teachers to begin their teaching, colleges must design programs of study considerably different from the traditional "major." Certain courses of greater significance to the future teacher must form the central core for teacher preparation. During postgraduate, summer-school, and other study, teachers should be encouraged to broaden their background to meet at least the minimal requirements outlined here.

References

1. W. E. Armstrong and T. M. Stinnett, *A Manual on Certification Requirements for School Personnel in the United States* (National Education Association, Washington, D.C.), published annually; W. G. Marburger, "Science training for prospective science teachers," *School Sci. and Math.* **56**, 21 (1956); C. M. Pruitt, *Science Educ.* **36**, 184 (1952).
2. *School Sci. and Math.* **46**, 107 (1946).
3. P. Johnson, *The Teaching of Science in Public High Schools: U.S. Office of Educ. Bull. No. 9* (Government Printing Office, Washington, D.C., 1950).
4. *Manpower for Research* (Government Printing Office, Washington, D.C., 1946), p. 105.

ASSOCIATION AFFAIRS

Amendment to Constitution

At the 1957 meeting of the Council of the American Association for the Advancement of Science, the Board of Directors will recommend changing the constitution of the Association to include past presidents as members of the Council. The specific change will be an amendment to Article IV, Section 2, which defines the membership and voting privileges of the Council, and will consist of insertion of the words *all past presidents* in the list of officers who serve as members of the Council.

This change is proposed as a means of putting into effect the wishes expressed by the Council last December in instructing the Board to "consider ways by which the interest of the past presidents of the American Association for the Advancement of Science may be maintained and their wisdom and experience utilized to the benefit of the Association."

This announcement is published to accord with the provisions for amending the constitution, which require publication at least one month prior to the December meeting of the Council.

AAAS-Campbell Award for Vegetable Research

The new AAAS–Campbell Award for Vegetable Research has just been established by the Campbell Soup Company and will be presented for the first time this year. The award consists of $1500 and a bronze medal, given for "an outstanding single research contribution, of either fundamental or practical significance, relative to the production of vegetables, including mushrooms, for processing purposes, in the fields of horticulture, genetics, soil science, plant physiology, entomology, plant pathology, or other appropriate scientific areas." Work in food technology and work in food processing are *not* included; the emphasis is on basic research and its application to crop production, prior to crop utilization or crop production.

The one or more papers reporting a candidate's single research contribution should have been published, or accepted for publication, in a recognized scientific journal not more than 2 years prior to the date the award is to be granted. Competition is open to all residents of the United States and Canada. Travel expenses are provided for the recipient to attend the AAAS meetings to receive the award in person.

The Award Committee is composed of a chairman appointed by the AAAS and official representatives of six affiliated societies: the American Phytopathological Society, the American Society for Horticultural Science, the American Society of Agronomy, the American Society of Plant Physiologists, the Entomological Society of America, and the Genetics Society of America.

Members of this year's Award Committee are as follows: Louis P. Reitz (vice-president for AAAS Section O—Agriculture), USDA, Agricultural Research Service, Beltsville, Md., chairman; G. J. Haeussler (Entomological Society of America), USDA, Agricultural Research Service, Beltsville, Md.; Sterling B. Hendricks (American Society of Plant Physiologists), USDA, Plant Industry Station, Beltsville, Md.; Iver J. Johnson (American Society of Agronomy), Iowa State College, Ames; F. C. Stark, Jr. (American Society for Horticultural Science), University of Maryland, College Park; G. Ledyard Stebbins, Jr. (Genetical Society of America), University of California, Davis; E. E. Wilson (American Phytopathological Society), University of California, Davis. Nominations for the Campbell Award may be made to any member of the Award Committee.

AAAS Meeting in Indianapolis

Since the appearance of the preliminary announcement of the fourth Indianapolis meeting of the American Association for the Advancement of Science, which will be held from 26 to 30 Dec. inclusive [*Sci. Monthly* 85, 41 (1957)], the symposia and other programs listed there have been developed and augmented.

From such program details as the names and addresses of the authors of the hundreds of papers, and from such data as the advance registrations and applications for housing accommodations, which have been received in increasing volume since July, it is quite apparent that this year's AAAS meeting—the 124th—will enjoy an excellent attendance and that all sections of the United States and many foreign countries will be represented.

The Annual Exposition of Science and Industry will fill the large Egyptian Room of the Murat Temple and would, alone, be worth a trip to Indianapolis.

As the outline of symposia shows, virtually no principal field of science will be neglected, and the number and variety of special events, characteristic of AAAS meetings, are greater than usual. A conspectus of these follows.

AAAS General Symposium

This year the Association-wide program, *The Moving Frontiers of Science* (II), which has the theme "Ideas That Mold Our Work," will include presentation of three addresses. On the evening of 26 December, S. S. Stevens of the department of psychology at Harvard University will discuss "Measurement and man," and G. C. McVittie of the University of Illinois Observatory will discuss "Distance and relativity." On the afternoon of 27 December, T. Dobzhansky of the department of zoology at Columbia University will discuss "Evolution at work," and there will be a commentary on the program and an opportunity for questions to be addressed to the three speakers. Both sessions will be under the chairmanship of F. S. C. Northrop, Sterling professor of law and philosophy, Yale University. The program has been arranged by the Association's Committee on AAAS Meetings, of which Harry C. Kelly, National Science Foundation, is chairman, and Howard M. Phillips, Arthur W. Galston, Frank K. Edmondson, and F. E. Cislak are members.

Conferences and Special Programs

In recent years, in addition to the Academy Conference, several conferences have become recurrent events at AAAS meetings. Also, not infrequently, interest in special subjects may develop to the point where a special program is arranged. These conferences and special programs are open to all who are interested. *Academy Conference,* 28 Dec.; *Conference on Scientific Editorial Problems,* 26 to 29 Dec.; *Conference on Scientific Manpower,* 30 Dec.; *Mathematics Instruction,* a program of AAAS Section A–Mathematics, cosponsored by the National Council of Teachers of Mathematics and the AAAS Cooperative Committee on the Teaching of Science and Mathematics, arranged by John R. Mayor, educational director, AAAS, 27 Dec.; *Social Aspects of Science as Illustrated by the Radiation Problem,* a general session sponsored by the AAAS Committee on Social Aspects of Science, arranged by Chauncey D. Leake, chairman, 29 Dec.

Special Sessions

One of the characteristic and most important features of the annual meetings of the Association is the series of outstanding general addresses by distinguished experts, sponsored by organizations that meet regularly with the AAAS. These special events are joint sessions with the Association and are open to the general public of the city in which the meeting is held.

Special Address of the Biometric Society, Eastern North American Region; 27 Dec.; Boyd Harshbarger, department of statistics, Virginia Polytechnic Institute, and president, Biometric Society, Eastern North American Region, presiding. "Smoking and lung cancer: an example of the interpretation of statistical data in the observational sciences," by Sir Ronald A. Fisher, Arthur Balfour professor of genetics, Cambridge University, England.

Joint Annual Address of the Society of the Sigma Xi and the Scientific Research Society of America; 27 Dec., 8 P.M.; Ballroom, Hotel Claypool; George H. Boyd, dean of the Graduate School, University of Georgia, and president, Society of the Sigma Xi, presiding. "The fickle fashions of science," by Crawford H. Greenewalt, president, E. I. duPont de Nemours and Company, Inc. Edward R. Weidlein, director, Mellon Institute for Industrial Research, and chairman, Scientific Research Society of America, will award the William Procter Prize.

Annual Address of United Chapters of Phi Beta Kappa; 27 Dec.; A. Logan Steele, president, Indianapolis Association of Phi Beta Kappa, presiding. "A long search for understanding," by Elvin C. Stakman, emeritus chief, Division of Plant Pathology and Botany, University of Minnesota, and past president, AAAS.

AAAS Presidential Address; 28 Dec.; Laurence H. Snyder, dean of the Graduate School, University of Oklahoma, and president of the AAAS, presiding. "The inexorable problem of space," by Paul B. Sears, director. Conservation Program, Yale University, and retiring president of the AAAS. Preceding the address, A. H. Fiske, vice president of Eli Lilly and Company and general chairman of the Indianapolis meeting, will speak briefly. Following the address there will be an informal presidential reception in the ballroom and adjacent rooms of the Hotel Claypool. All registrants and members of the local committees are cordially invited to attend.

Annual Lecture and Film of the National Geographic Society; 29 Dec.; Paul A. Scherer, treasurer of the AAAS, presiding. "The *Bounty* and Pitcairn Island," by Luis Marden, foreign editorial staff, National Geographic Society.

Topical Index of Symposia

AAAS General Symposium. "Ideas that mold our work."

Mathematics. "Mathematics instruction"; "Mathematics of guided missiles"; "Computer research and applications"; "The teaching of mathematics."

Physics. "Wavelength standards and problems of vacuum ultraviolet spectroscopy"; "Spectra of lanthanides and actinides: isotope shift"; "theory of spectra: applied spectroscopy"; "Some recent advances in physics."

Chemistry. "Acetylene chemistry" (two sessions);

"Pyridine chemistry" (two sessions); "Significant trends in the chemistry of disease."

Astronomy. "Cepheid variable stars."

Geology and Geography. "Continental glaciation and its geographic importance as an environmental factor" (four sessions); "Mississippian and Pennsylvanian rocks of the Midwest" (two sessions); "Karst phenomena"; "Cave fauna of the Ohio River Valley."

Zoological Sciences. "Current understanding of pituitary function"; "Low level irradiation" (two sessions).

Biological Sciences. "Some unsolved problems in biology, 1957." Part I: "Geographic distribution of contemporary organisms"; Part II: "Biochemistry and embryology."

Botanical Sciences. "Polarity, heads or tails?"

Psychology. "Human engineering: research planning for space flight"; "Psychopharmacology"; "Effects of early experience on behavior"; "Contemporary research on psycholinguistics"; "Decision theory, signal detection, and psychophysics"; "Problems and progress in statistical learning theory."

Social and Economic Sciences. "Social aspects of urban agglomeration"; "Current researches on population"; "Advances in theoretical criminology and penology"; "Advances in interdisciplinary approaches to crime and delinquency"; "Police-crime symposium"; "Advances in police administration"; "Advances in scientific crime detection."

History and Philosophy of Science. "Can science provide an ethical code?"; "Organization for humans, cells, and artifacts."

Engineering. "Man and his environment" (two sessions).

Medical Sciences. "The human integument–normal and abnormal" (four sessions); "Premedical and predental education"; "Space medicine" (two sessions); "Rehabilitation of the mentally ill: social and economic aspects" (four sessions).

Dentistry. "Physiology and pharmacology of fluorides" (three sessions).

Pharmacy. "A pharmacological approach to mental illness"; "Recent trends in medications"; "Metric implementation in pharmacy, medicine, and chemistry."

Agriculture. "Biological and chemical control of plant and animal pests" (four sessions).

Industrial Science. "Science, technology, and general welfare in a capitalistic society"; "Some areas in industrial microbiology."

Education. "Problems of gifted children"; "Teaching the major concepts"; "Methods and techniques—problem solving in biology"; "Strengthening some classroom foundations"; "Teaching the major concepts"; "The junior museum and its relation to the public schools"; "Stimulating interest in nature study"; "Natural history of Indiana and the Midwest."

AAAS Business Sessions

Meetings of the Board of Directors: The Board of Directors of the Association will meet Friday, 27 Dec., at 9:30 A.M. Dates and hours of subsequent sessions of the Board of Directors during the meeting will be decided at this first session.

Council Meetings: The Council of the Association will meet Friday, 27 Dec., at 4 P.M. in the Chateau Room, Hotel Claypool. A second session of the Council is scheduled for Monday, 30 Dec., at 9 A.M. in the same room.

Subjects to be considered by the Council (in addition to the agenda prepared) are usually first brought before the Board of Directors through the executive officer. During the meeting, communications for the Board of Directors should be submitted in writing and left at the Hotel Claypool mail desk, addressed to Dr. Dael Wolfle.

Meeting of all Section Chairmen and Section Secretaries. There will be a luncheon and business meeting of the officers of all AAAS sections on Sunday, 29 Dec., in the Empire Room, Hotel Claypool, at 12 noon. Dael Wolfle and Raymond L. Taylor are cochairmen.

Hotel Headquarters

The Hotel Claypool is the official headquarters of the AAAS Indianapolis meeting; there the Council of the Association will meet and other business sessions will be held. The press room—for receipt of authors' abstracts and distribution of press releases—is in the Florentine Room on the mezzanine floor.

The Main Registration–Information Center, the Visible Directory of Registrants, the AAAS Office, the AAAS Science Theatre, and the Annual Exposition of Science and Industry will all be located in the Murat Temple.

A list of the headquarters of the 18 sections and participating societies appeared in the August issue of *The Scientific Monthly.*

Programs of the AAAS Science Theatre, a list of the exhibitors (together with descriptions of their exhibits) and lists of the members of the local committees are omitted here because of space limitations.

For all program details, see the General Program–Directory, available early in December.

RAYMOND L. TAYLOR
Associate Administrative Secretary

BOOK REVIEWS

Discovery of the Universe. An outline of the history of astronomy from the origins to 1956. Gerard de Vaucouleurs. Macmillan, New York, 1957. 328 pp. $6.

This translation from the original French edition, published in 1951, includes additional material to bring the state of astronomical discovery up to the present date. The author has fulfilled his aim—"giving . . . readers a comprehensive survey of the whole history of Astronomy in a few hundred pages." Naturally, a choice had to be made in the inclusion or exclusion of lesser astronomical discoveries and the details of their underlying meaning. I have no real objections to the proportionate values assigned to the discoveries in terms of space given in this work.

Somewhat more than one-third of the book is taken up with the progress made in the 20th century; this emphasis is fully justified and gives the book its freshness and individuality. The advances in instrumental technique in the last 50 years have contributed to rapid extensions of knowledge that were previously impossible, and although we do not have the benefit of perspective in evaluating all of the contemporary discoveries, up-to-date general surveys, which have been lacking, are of great interest.

The author has emphasized achievements, while the long, hard, uncertain, and sometimes devious paths which ultimately lead to progress are minimized, as is necessary for a survey. Nevertheless, to get a truer picture of the steps in astronomical progress, one must continually read between the lines; anyone actively engaged in scientific research has a natural aptitude for imagining the stumbling blocks of systematic errors, or the limitations of equipment, and so on, which plague the astronomer as he treads the way to enlightenment and success.

This book should be of value in placing astronomical discoveries for the amateur and for the student who is already familiar with astronomical terms and who has absorbed the fundamental notions of this science. Also, the professional worker in an allied scientific field will find the network of discovery a fascinating one. The survey nature of this book should stimulate the reader to further reading.

Only a few minor errors and misleading statements were found, such as the statement that almost all stars down to the 11th magnitude are included in *Argelander's Catalogue*; down to the 10th magnitude is closer to the truth. The index of names is useful in connection with the text but should not be taken out of context and used as a listing of the first 500-odd names in astronomy.

Unfortunately, the reproduction does not do justice to the magnificent contemporary photographs included in this volume. If this type of book had to be "cheered up" with plates (I am not convinced of this necessity), then the method of reproduction should have been different (increasing the cost of the book, alas), or some historical illustrations might have been used.

SARAH LEE LIPPINCOTT

Swarthmore College

The Next Hundred Years. Man's natural and technologic resources. Harrison Brown, James Bonner, and John Weir. Viking, New York, 1957. 193 pp. Illus. $3.95.

What is new and newsworthy about this book is not so much the subject matter as the fact that it owes its origin to an experiment in communication between academic scientists and corporation executives. Any effort to peer into the future of our scientific-technologic-industrial civilization will interest the management of modern corporations whose life-span knows no biological limits. And when the forecasters are of the caliber of Harrison Brown, James Bonner, and John Weir, corporate policy makers are likely to be influenced by the probabilities and trends laid before them.

The experience of dealing with industrial leaders has also left its mark on the authors. The book contains the most lucid and concise estimate of man's natural and technologic resource potential yet in print. Aware of the business executive's cult of the one-page memorandum, the writers have spared no effort to compress their facts, arguments, and conclusions within the attention span of the typical corporate official. In 150 pages, the reader will find a distillate of Brown's thoughts on the spread and intensification of our industrial culture, so ably presented in *The Challenge of Man's Future* (1954), Bonner's appraisal of the world food-producing capabilities in the light of rapidly growing populations, and Weir's keen analysis of how our intellectual resources must be mobilized to devise

new ways to use the materials with which the earth is endowed.

The conclusions will not kindle the flame of either Cornucopian or neo-Malthusian. But they will kindle the general reader's interest in the long-range outlook for human survival. The future, viewed solely from the technologic standpoint, offers material resources ample to provide for a much larger population and a somewhat more prosperous one than the world supports today. The difficulties that must be overcome before a more abundant life becomes a reality for all the world's people are primarily social. How can a vast reservoir of technical brainpower be created on short notice? Can war be avoided in a period of growing competition for critical raw materials, as more nations acquire the capacity to wage unrestricted warfare? Will it be possible to increase the amount of food produced each year, and in every country, as rapidly as the number of people is likely to grow? Can the benefits of scientific and technologic innovations be spread in time to answer the cry for higher levels of living?

The intelligence needed to find the solutions to these problems is the scarce commodity! In the author's own words, "When we take the very long view of man's world in the next century we see that the main problems are less those of technology than they are those of men's getting along with other men, communicating with other men, and organizing themselves in such a way that their genius and imagination can be vigorously applied to the problems that confront them."

PETER M. STERN

Conservation Foundation

Health and Medical Care in New York City. A report by the Committee for the Special Research Project in the Health Insurance Plan of Greater New York. Published for the Commonwealth Fund by Harvard University Press, Cambridge, Mass., 1957. ix + 275 pp. Illus. $7.50.

"The Health Insurance Plan of Greater New York, launched early in 1947, was designed to be a practical demonstration of the values to families with moderate incomes of comprehensive prepaid medical care rendered by group practice units called medical centers. The physicians in these centers were to accent the preventive services now possible in medical practice as well as to take care of illness and injury. The group practice units were to be medical partnerships compensated by capitation payments for enrollees, and not by fees for medical services."

Because of the need for factual data concerning the influence of this type of medical care program on the health of the population, a Planning Committee for the Health Insurance Plan Special Research Project was formed in 1951. This volume reports the results of the study which was prepared by the planning committee and executed under the direction of a steering committee. The former was chaired by Selwyn D. Collins and the latter by Lowell J. Reed. Both committees are studded with the names of well-qualified and nationally known experts in the field of health programs. The study was supported by liberal grants from the Commonwealth Fund and Rockefeller Foundation.

"Viewed broadly, there was need to know about the H.I.P. experience for the light that it could throw, first, on the need for medical care by population groups; second, on the volume and kind of medical service utilized by persons covered by this Plan, as compared with the services sought and received by similarly circumstanced persons not so covered; and third, on the reported conditions and services rendered to categories of enrollees over periods of years, that is, the so-called longitudinal studies. This report is concerned with the first two of these three purposes. A later series of papers will be devoted to the fulfillment of the third objective."

"Because H.I.P. had no knowledge of the extent to which enrollees might have been using the services of physicians who were not in H.I.P., and also because there were no data on medical care in New York City with which the H.I.P. experience could be compared, this Advisory Conference recommended that a Household Survey be made both of H.I.P. families and of other families in New York City that would provide the data necessary for a clear and broad understanding of the H.I.P. experience. Thus the survey was basically designed to examine two samples of households, one drawn from the rolls of H.I.P., the other from the households in the general population."

The methods used, the type of interview, and the carefully prepared and complex questionnaire were well calculated to answer pertinent questions. One might wish that the study could have been based on documented data rather than on the interview method with its obvious technical difficulties. Those who conducted the study, recognizing this weakness, were cautious to interpret the findings, which appear to be valid, within the limits of accuracy of the method.

Analysis of the demographic characteristics of the households and their members showed that the two groups were reasonably comparable. The study

then proceeds with a comparison of the two samples in respect to physician contacts, morbidity, disability, medical care, hospitalization, and similar factors, together with their relationship to the age, sex, level of education of the head of the household, and labor force status of the two samples of households. Space permits no more than a cursory summary of the findings.

Among the Health Insurance Plan households as compared with the New York City sample, physician contacts were greater, a higher percentage retained family physicians, and the services of pediatricians were utilized to a greater extent. These results are not surprising in view of the fact that the H.I.P. group had prepaid for these services.

More surprising, however, were the results with respect to the incidence of medical conditions. "The facts are that (1) acute non-disabling illnesses had a greater frequency in the H.I.P. sample than in the New York City sample even when differences in labor force status, age, sex, or education of the head of the household are taken into account; (2) days lost by persons in the labor force because of acute disabling conditions were greater for the H.I.P. sample than for the New York City sample. While it is true that factors other than a person's definition of illness enter into a decision to remain home from work, the point of departure must still be the person's conclusion that he is not well. The facts cited strongly suggest that membership in a plan for prepaid comprehensive insurance has in some way produced a higher reported frequency of acute illness and of disability from such illness."

"That factors other than purely economic ones influenced the amount of illness reported is indicated by the fact that within the H.I.P. sample, as in the New York City sample, the frequency of acute conditions varied directly with increasing education of the head of the household. We must conclude that education itself or some variable related to education other than economic status influences the level of recognition of illness. The hypothesis proposed suggests that the influence of H.I.P. on a population is analogous to that shown by a higher level of education of the household head: in both cases there is a higher frequency of acute illness reported which reflects a lowered threshold for recognition of deviation from feeling well."

The conclusion I draw is that the ready availability of health services without economic barriers tends to make the insured individual more health conscious. If this is true, comprehensive programs, such as Health Insurance Plan, should in the long run improve the health of their subscribers. It must be remembered, however, that Health Insurance Plan was only 5 years old when this study was conducted in 1952 and that there were inadequate data to test this hypothesis. The planning committee undoubtedly proposed to test it more fully in future research projects.

The volume contains a vast amount of data which will be useful in guiding future studies and in planning the organization of comprehensive medical care programs. A useful by-product of the study is its contribution to methodology in the growing field of morbidity surveys. The study opens new vistas for research. It raises more questions than it answers and is therefore provocative. It is well written, objective, and conservative in its presentation of findings.

HENRY N. PRATT

New York Hospital

Rocks and Minerals. A guide to familiar minerals, gems, ores, and rocks. Herbert S. Zim and Paul R. Shaffer. Simon and Schuster, New York, 1957. 160 pp. Illus. $2.50.

Rocks and Minerals, the 11th book in the Golden Nature Guides Series, published by Simon and Schuster, is illustrated with more than 400 color pictures of specimens of rocks and minerals—diamonds, emeralds, and jade as well as ores from which gold, copper, uranium, and tin are extracted. The book is pocket size. It gives suggestions to the amateur on collecting and identifying specimens and lists books, magazines, and exhibitions where specimens can be studied.

Reptiles. Angus d'A. Bellairs. Hutchinson's University Library, London, 1957 (distr. by Rinehart, New York). 195 pp. Illus. $1.50.

Approximately one-fourth of this book is devoted to reptilian anatomy and physiology, one-half to a synoptic view of reptiles past and present, and one-fourth to the biology of lizards and snakes, in that order. A large series of small black and white figures illustrate representatives of all orders and many infraorders as well as various morphological features. Although the figures are good, they are grouped many to a page with the result that an illustration is rarely adjacent to the relevant text.

Angus Bellairs' intention was "to provide, however incompletely, a kind of synthesis of the dif-

ferent sorts of knowledge available on reptiles" for students of zoology, naturalists, and the general reader. We have come to expect from our British colleagues a rather scholarly approach to popular writing, which is certainly better than the pap so often published in this country. Bellairs does not disappoint us in this regard.

Those familiar with Bellairs' research know his competence to write on reptilian morphology, and the first section draws heavily on that research as well as on the recent work of others in that field. In fact, one of the best aspects of this little book is that so much of the information is based on papers published in the last 5 years.

However, in my opinion, too much of the information is descriptive rather than functional or ecological. This is not to say that these aspects are ignored. But the emphasis is such that the intriguing ideas that have come out of the study of reptiles are understated and half buried.

Bellairs' book is a competent, accurate review of his subject, written for mature minds. Yet it fails to communicate to the student or general reader the excitement that exists in our ivory towers. The communication of that excitement is probably one of the most important functions of popular writing.

ROBERT F. INGER
Chicago Natural History Museum

Annual Epidemiological and Vital Statistics, 1954. World Health Organization, Geneva, 1957 (order from Columbia University Press, New York). 617 pp. $10.

Annual Epidemiological and Vital Statistics, 1954, is the seventh yearbook of epidemiological and vital statistics published by the World Health Organization. The previous volumes were published in two parts: "Vital statistics and causes of death" and "Cases of and deaths from notifiable diseases." The present edition includes a third part, "Statistics of health personnel, hospital establishments and vaccinations."

Lascaux and Carnac. Glyn Daniel. Macmillan, New York; Lutterworth, London, ed. 2, 1957. 127 pp. Illus. $3.

Lascaux and Carnac was written for the summer tourist interested in a trip to the most spectacular archeological sites in France. These are the caves of the Dordogne area, painted by prehistoric man during the Ice Age, some 10,000 to 40,000 years ago, and the huge stone alignments and megalithic tombs of the Morbihan region of southern Brittany, built in the second millenium before Christ. These two areas have other attractions for the tourist—truffles and *fois gras* in the Dordogne, sea food in Brittany, and delicious local wines. Glyn Daniel is hardly less interested in extolling the French cuisine than in describing the spirited style of the cave art or the mysteries of the megaliths. "Only the most arid archaeology flourishes in France (or elsewhere) without good food and wine. This book pretends, in the most modest way, to be a mild gastro-archaeology of the two areas" (from the preface).

We are given, therefore, information about places to eat and to spend the night as well as about highways and railroads to reach these regions. Once there, we are given an itinerary to follow, beginning, in the Dordogne, with the local museum, to get a glimpse of what has been excavated at the prehistoric sites, and ending at Lascaux, the most famous of the painted caves. A similar program is outlined for the return toward England through the country of the megalithic monuments, around Carnac.

Daniel is also interested in local French history and offers us bits of information about events that range in date from the invasion by Caesar to that by Hitler. The text is illustrated by excellent maps and by a few well-chosen photographs, including a double-page aerial view of the impressive Carnac alignments.

Daniel is a Cambridge archeologist whose *A Hundred Years of Archaeology* is a standard reference work on the history of this discipline in Europe, and he has also written *The Megalith-Builders of Western Europe* (1956). His professional training and personal familiarity with French archeology have equipped him well to act as guide. His own interest is not so much in what the sites reveal about the life of the Paleolithic hunters or the megalith-building farmers and traders as it is in these places as landmarks in the history of science. The sites are presented, therefore, as the scenes of important and often dramatic discoveries or as the sources of data that precipitated or settled scientific controversy. For a comprehensive account of the archeological cultures that produced the cave paintings or the enormous stone monuments, we are referred to the more systematic works or scholarly articles cited in the footnotes. This book is not really for the beginner, since some prior knowledge of archeology is useful as a background for the anecdotes about the sites and the savants who studied them.

The weakness of the book lies in the fact that it contains so many different kinds of information —that it is made up, as Daniel writes in the

preface, of "some of the things I would say if I met the reader at a café table at Carnac or on a hotel terrace in Montignac or Les Eyzies." While all of these chatty observations are intrinsically interesting and can supplement a textbook on archeology or French history and a Baedeker or *Guide Michelin*, they remain scrappy in character. It would be better to read this little volume while actually traveling in the scenes it describes, so that the continuity of one's own personal experiences might provide a greater coherence.

FREDERICA DE LAGUNA

Bryn Mawr College

Plant Classification. Lyman Benson. Heath, Boston, Mass., 1957. xvi + 688 pp. Illus. $9.

If taxonomy is at times a dry subject, concerned with teaching the laws of nomenclature or a simple pigeonholing of flat and long-dead bits of plants, it ought to be for the beginning student a bright challenge to a new world of knowledge and of fresh, living organisms. Lyman Benson has presented us with a textbook of plant taxonomy possessed with the sparkle of this challenge. "Modern" in its presentation, *Plant Classification* is studded with handsome illustrations and livened with keys, tables, maps, diagrams, and a tasteful variety of type styles. The author's care in detail and in maintaining an internal consistency remarkable in so large a work, and his engaging style, by which a peltate leaf resembles "a silver dollar balanced on the end of a pencil, or . . . a mushroom or an umbrella, except that typically the edges do not droop," add to its attractiveness.

The book proposes to guide the student through the processes of collection and identification of vascular plants, to an appreciation of the bases for their classification and awareness of the association of species in natural vegetation. At the heart of Benson's text, in its system of classification of the orders and families of flowering plants, is a major innovation. Rejecting attempts at linear phylogenetic systems, he has classified his 56 recognized orders of dicotyledons in five "convenient but partly artificial groups," easily understood by the student. The groups are based on classical floral features of ovary position, free or fused petals, and possession of or lack of catkins. Combining parts of the systems of Engler and Bessey, with modification, he arranges the orders of angiosperms in a kind of "exploded cactus," according to their divergence in specialization from the "primitive" condition represented by modern Ranales and Alismales.

This attempt to facilitate the teaching of a major segment of the plant kingdom and also incorporate most of what knowledge we have of relationships among modern orders deserves commendation. The inclusion of teaching keys for all higher taxa in North America and of concise diagnoses of *all* classes, orders, and families of vascular plants should guarantee wide usage of this new system.

Other noteworthy features of the book are a glossary of more than 1200 terms, special keys prepared for the subdivisions of large families like the Compositae and Gramineae, and an adequate discussion of paleobotanical evidence for relationships in the pteridophytes and gymnosperms. The treatment of the flora and vegetational regions of North America given in the concluding chapter is the best of its kind I have seen.

Because of the profuse illustrations there are inevitably a few pictures of reduced quality, artistically or photographically. And probably some phylogenists will disagree with the author's treatment of classes and orders in the gymnosperms. But the book is by all measures a distinguished addition to the literature of plant taxonomy.

KENTON L. CHAMBERS

Yale University

A Textbook of Plant Virus Diseases. Kenneth M. Smith. Little, Brown, Boston, Mass., ed. 2, 1957. 652 pp. Illus. $12.

It must be said at the outset that this is not what most of us would understand by the word *textbook*. There is no introductory material, except for a brief preface, or any general discussion of plant viruses and the mechanisms by which they cause disease. The book is more in the nature of an encyclopedia or handbook, with all the material arranged alphabetically according to the common English name of the virus (to avoid the controversial question of the nomenclature of plant viruses). These differences between the nature of the text and the title do not, however, mean that the book is not a good one; on the contrary, it represents an extremely useful compilation of what is presently known about plant viruses and the diseases they cause.

Since the first edition appeared, 20 years ago, the number of known plant viruses has increased greatly, and in the present edition, more than 300 separate viruses, not counting strains, are dealt with. This increase in material, plus a new method of arranging it, makes this an entirely new book.

Under each alphabetic heading the author discusses, usually, the nature of the virus and its transmission, the diseases it produces, the host range, the geographic distribution, and methods of

control. Since, in some cases, information about one or more of these topics is scanty or lacking, the material related to a given virus varies from a few lines to several pages. There are 93 halftone illustrations.

Because of the alphabetical arrangement, there is no need of a general index, but there are an index of synonyms of the viruses and a bibliography of more than 1000 titles. There are also an addendum and short bibliography for it.

This volume should be indispensable as a reference book to all who are interested in the field. It should be particularly useful to American workers because of its compact summary of the fine recent work of the British plant virologists.

WILLIAM C. BOYD

Boston University

Modern Science and the Nature of Life. William S. Beck. Harcourt, Brace, New York, 1957. xvii + 302 pp. $5.75.

The scientists of America—the more thoughtful ones at least—have become greatly preoccupied with the general public misunderstanding of the nature of science. Many of them feel that they have failed "in their duty to communicate, in a manner intelligible to nonscientific readers, a sense of what is going on in science today, where it is heading, where it is not heading, and why not." William S. Beck, a young medical scientist who has been associating with philosophers and humanists at the same time that he has been pursuing his biochemical researches, shares this feeling. This has led him to write *Modern Science and the Nature of Life*. The book, as he states in the preface, "is an attempt to clear my own conscience on this score."

The book starts with a discussion of the nature of science and of the relations between science and general human culture. The author, here and throughout the book, stresses the relativity of scientific "truth," the futility of the quest for certainty. He touches on science in the ancient and medieval worlds and on the rise of modern science in the 17th and 18th centuries, giving emphasis to the beginnings of biology.

The second part of the book is concerned with the events and controversies of 19th-century biology: the cell theory, spontaneous generation, evolution, vitalism and mechanism, and the nature of life. This brings the author to the 20th century, which he calls "the age of analysis." This section of his book is largely devoted to an explanation of contemporary philosophy of science, with section headings like "The decline and fall of the absolute"; "Words, conceptions, models, and meanings"; "The nature of explanation"; and "The creative act."

In the fourth and final section of the book, the author turns to "contemporary biology, its problems and prospects." He gives here a lucid account of the latest ideas about the nature of the gene and about viruses and of the exciting things being done by contemporary students of the bacteriophages. He explains desoxyribonucleic acid and ribonucleic acid, makes a thoughtful excursion into the cancer problem, and, in general, does a remarkably fine job of conveying the "feel" of contemporary biological research.

It seems to me, then, that Beck has made an excellent summary of "modern science and the nature of life" for nonscientific readers. Whether these nonscientific readers will read the book or not is another question. I am afraid that he has not written in a way to overcome the passive resistance of the "lay" public and that his readers will be mainly fellow-scientists or people already, for some reason, interested in science—people who have the least need of his message. But scientists who read the book will inevitably also learn new things and gain new insights, especially from the last section, on contemporary biology.

MARSTON BATES

University of Michigan

Margarine and Other Food Fats. Their history, production, and use. M. K. Schwitzer. Interscience, New York, 1956. 385 pp. + plates. $7.

This book is a well-written, straightforward presentation of the evolution of a food-processing industry. It illustrates nicely, for one out of a multiplicity of processed foods, how food technology has risen with the tide of industrial development in providing the food requirements of increasingly technologically dependent populations.

Although the book is focused primarily on margarines, other manufactured food fats are kept in proper perspective. Natural fats such as butter, lard, and olive oil are considered, together with the manufactured fats, as part of the total food fats and oils industry. The main emphasis is on technology, but the historical and economic aspects are adequately covered, directly or by appropriate references.

While the book is written primarily for those concerned with the production of margarines, cooking fats, shortenings, and so forth, it will also serve those less directly concerned, such as the chemical engineer, the architect of industrial plants, and the economic historian. Nutritional scientists and members of the legal profession may

profit from the information about the raw materials and production processes described but will find little of direct use in the cursory chapter on dietary and legal aspects. However, the author has accomplished his purpose well and has offered a good account of an interesting industry.

LEROY VORIS

National Research Council

The Life of Arthur Stanley Eddington. A. Vibert Douglas. Nelson, New York, 1957. 207 pp. Plates. $6.25.

Eddington was a titan of astronomy whose contributions to the theories of stellar motions, relativity, stellar structure, and interstellar matter had a vital and lasting influence on the development of astrophysics in this century. His life spanned the years in which modern physics was being developed, and he was quick to see the important astrophysical consequences of the work of Einstein, Dirac, R. H. Fowler, and many others. What is more, he did not hesitate to communicate his ideas to the public, and, paralleling his scientific articles and books, there runs a series of popular expositions, written in a delightful style.

In contrast to his active scientific life, his personal life was uneventful. He was a quiet, introspective man with deep religious feelings; he had few intimate friends and found relaxation from his work by bicycling.

A. Vibert Douglas, a former student of Eddington's and now dean of women at Queen's University, Ontario, Canada, has succeeded in combining these widely differing facets of Eddington's life to present a picture of the man as a whole. She has chosen in many places to let Eddington speak for himself, and there are numerous nonmathematical excerpts from Eddington's books, illustrating his points of view and his command of language. Surely this will encourage many readers to go to the sources and experience the enjoyment of reading the original works.

One of the most interesting portions of the book is devoted to Eddington's scientific tussles with J. H. Jeans. The author gives, in very abbreviated form, the points at issue; the interested reader may also wish to read the relevant parts of E. A. Milne's biography of Jeans for a discussion more sympathetic to the other side.

At the time of his death in 1944, Eddington was at work on a book, published posthumously under the title *Fundamental Theory*. This work has been severely criticized, and whether it will be his crowning achievement or most spectacular failure cannot yet be determined. A chapter is devoted to this work, pointing out the goals Eddington was seeking and not hesitating to quote his critics.

A concluding bibliography of his publications testifies to the scope of Eddington's interests and to his remarkable productivity.

MARSHAL H. WRUBEL

Indiana University

The Direction of Research Establishments. Proceedings of a symposium held at the National Physical Laboratory 26–28 Sept. 1956. H.M. Stationery Office, London, 1957 (order from British Information Services, 45 Rockefeller Plaza, New York). $4.50.

This symposium, held at the National Physical Laboratory last year, was the first of its kind to be held in the United Kingdom and was attended by delegates from 16 different countries, including the United States. The proceedings volume contains the papers presented at the symposium, together with a record of the discussions. The topics discussed cover a wide range of problems common to large research laboratories, including staffing, finance and general organization, physical lay-out, and communication.

Books Reviewed in SCIENCE

4 October

Gas Chromatography, A. I. M. Keulemans (Reinhold). Reviewed by A. B. Littlewood.

The Calculation of Atomic Structures, D. R. Hartree (Wiley; Chapman & Hall). Reviewed by R. S. Mulliken.

Mammals of the Great Lakes Region, W. H. Burt (University of Michigan Press). Reviewed by W. J. Hamilton, Jr.

Notions de Cytologie et Histologie, M. Chèvremont (Desoer). Reviewed by F. Wassermann.

A Manual of Pharmacology and Its Applications to Therapeutics and Toxicology, T. Sollmann (Saunders). Reviewed by W. Cutting.

Progress in Low Temperature Physics, vol. 2, C. J. Gorter, Ed. (North-Holland; Interscience). Reviewed by C. T. Lane.

Pilot Plants, Models, and Scale-up Methods in Chemical Engineering, R. E. Johnstone and M. W. Thring (McGraw-Hill). Reviewed by J. M. DallaValle.

11 October

The Physiology of the Pituitary Glands of Fishes, G. E. Pickford and J. W. Atz (New York Zoological Society). Reviewed by O. H. Robertson.

Quantum Mechanics, H. A. Kramers (North-Holland; Interscience). Reviewed by F. J. Belinfante.

Advances in Protein Chemistry, vol. XI, M. L. Anson, K. Bailey, J. T. Edsall, Eds. (Academic Press). Reviewed by E. L. Smith.

The Proceedings of the Third International Conference on Electron Microscopy, London, 1954; V. E. Cosslett, chairman, editorial committee; R. Ross, General Ed. (Royal Microscopical Society). Reviewed by A. J. Hodge.

Mitochondria and Other Cytoplasmic Inclusions (Academic Press). Reviewed by W. [illegible] Duryee.

Clinical Toxicology of Commercial Products, M. N. Gleason, R. E. Gosselin, H. C. Hodge (Williams & Wilkins). Reviewed by W. Cutting.

Thermodynamics, E. A. Guggenheim (North-Holland). Reviewed by R. J. Bearman.

18 October

Automation in Business and Industry, E. M. Grabbe (Wiley; Chapman & Hall). Reviewed by A. King.

Isotopic Tracers in Biology, M. D. Kamen (Academic Press). Reviewed by H. Yagoda.

Report of the Conference on Recent Developments in Cloud-Chamber and Associated Techniques, N. Morris and M. J. B. Duff, Eds. (University College, London). Reviewed by H. R. Crane.

Psychological Aspects of Aging, J. E. Anderson, Ed. (American Psychological Assoc.). Reviewed by A. T. Welford.

Ageing in Industry, F. L. Clark and A. C. Dunne (Philosophical Library). Reviewed by W. C. Fitch.

Limited War, R. E. Osgood (University of Chicago Press). Reviewed by G. K. Tanham.

25 October

The Detection and Measurement of Infra-Red Radiation, R. A. Smith, F. E. Jones, R. P. Chasmar (Clarendon Press). Reviewed by D. J. Lovell.

Traité de Microscopie, A. Policard, M. Bessis, M. Locquin (Masson). Reviewed by O. W. Richards.

Corrosion and Wear Handbook for Water Cooled Reactors, D. J. DePaul, Ed. (U.S. Atomic Energy Commission).

Dictionary of Microbiology, M. B. Jacobs, M. J. Gerstein, W. G. Walter (Van Nostrand). Reviewed by F. B. Gordon.

The Modern Researcher, J. Barzun and H. F. Graff (Harcourt, Brace).

A History of Luminescence from the Earliest Times until 1900, E. N. Harvey (American Philosophical Society). Reviewed by W. D. McElroy.

Concepts of Force, M. Jammer (Harvard University Press). Reviewed by R. B. Lindsay.

New Books

The Detection and Measurement of Infra-Red Radiation. R. A. Smith, F. E. Jones, R. P. Chasmar. Clarendon Press, Oxford, England, 1957 (order from Oxford University Press, New York 11). 461 pp. $11.20.

Annual Review of Physical Chemistry. vol. 8. H. Eyring, Ed. Annual Reviews, Palo Alto, Calif., 1957. 534 pp. $7.

Atoms at Your Service. Henry A. Dunlap and Hans N. Tuch. Harper, New York, 1957. 178 pp. $3.50.

An Introduction to Fluid Mechanics and Heat Transfer. With applications in chemical and mechanical process engineering. J. M. Kay. Cambridge University Press, Cambridge, England, 1957 (order from Cambridge University Press, New York 22). 325 pp. $7.

Free Radicals in Solution. Cheves Walling. Wiley, New York; Chapman & Hall, London, 1957. 640 pp. $14.50.

Die Toxoplasmose. Bei mensch und tier. O. Thalhammer. Maudrich, Vienna, Austria, 1957 (order from Intercontinental Medical Book Corp., New York 16). 307 pp. $13.75.

Angular Momentum in Quantum Mechanics. A. R. Edmonds. Princeton University Press, Princeton, N.J., 1957. 154 pp. $3.75.

Introduction to Statistical Inference. Jerome C. R. Li. Edwards, Ann Arbor, Mich., 1957. 566 pp. $7.50.

Synthesis of Passive Networks. Theory and methods appropriate to the realization and approximation problems. Ernst A. Guillemin. Wiley, New York; Chapman & Hall, London, 1957. 759 pp. $15.

Quantitative Inorganic Analysis. G. Charlot and Denise Bezier. Translated by R. C. Murray. Methuen, London; Wiley, New York, 1957. 701 pp. $15.

The Visual Pigments. H. J. A. Dartnall. Methuen, London; Wiley, New York, 1957. 223 pp. $6.

An Encyclopaedia of Annual and Biennial Garden Plants. Faber & Faber, London, 1957 (order from Macmillan, New York 11). 488 pp. $12.50.

Behavior of Materials in the Earth's Crust. Papers and discussion from the second annual symposium of Rock Mechanics. Colorado School of Mines, 21–24 April 1957. Colorado School of Mines, Golden, 1957. 306 pp. $2.

The Faunal Connections between Europe and North America. Carl H. Lindroth. Wiley, New York; Almquist & Wiksell, Stockholm, 1957. 344 pp. $15.

Bacterial Fermentations. H. A. Barker. Wiley, New York; Chapman & Hall, London, 1956. 102 pp. $3.

The Shakespearean Ciphers Examined. An analysis of cryptographic systems used as evidence that some author other than William Shakespeare wrote the plays commonly attributed to him. William F. Friedman and Elizabeth S. Friedman. Cambridge University Press, London, 1957. 320 pp. $5.

A Classified Bibliography of Gerontology and Geriatrics. Supplement 1, 1949–1955. Nathan W. Shock. Stanford University Press, Stanford, Calif., 1957. 553 pp. $15.

Prehistoric Men. Robert J. Braidwood. Anthropology, Number 37. Chicago Natural History Museum, Chicago, ed. 3, 1957. 187 pp. Paper, $1.25.

Behaviour of Metals at Elevated Temperatures. Lectures delivered at the Institution of Metallurgists Refresher Course, 1956. Published for the Institution of Metallurgists. Iliffe, London; Philosophical Library, New York, 1957. 129 pp. $6.

Nomina Anatomica. Fr. Kopsch. Thieme, Stuttgart, Germany, 1957. 166 pp. $1.55.

Abbreviated Proceedings of the Oxford Mathematical Conference for Schoolteachers and Industrialists. Held at Trinity College, Oxford, 8–18 Apr. 1957.

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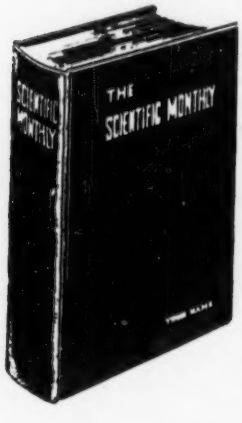

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Comparative Physiology of the Nervous Control of Muscular Contraction. Graham Hoyle. Cambridge University Press, London, 1957. 155 pp. $3.

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For Future Doctors. Alan Gregg. University of Chicago Press, Chicago, 1957. 174 pp. $3.50.

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The Divine Quest in Music. R. W. S. Mendl. Philosophical Library, New York, 1957. 265 pp. $7.50.

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6–8. Reliability and Quality Control, 4th natl. symp., Washington, D.C. (C. M. Ryerson, RCA, Bldg., 10–6, Camden 2, N.J.)

7–10. Radioactive Isotopes in Clinical Application and Research, 3rd internatl. symp., Bad Gastein, Austria. (Second Medical Clinic, Vienna Univ., Vienna, Austria.)

8–10. Northeastern Weed Control Conf., 12th annual, New York. (R. J. Aldrich, Farm Crops Dept., Rutgers Univ., New Brunswick, N.J.)

13–17. Society of Automotive Engineers, annual, Detroit, Mich. (Meetings Div., SAE, 29 W. 39 St., New York.)

20–24. American Inst. of Electrical Engineers, winter general, New York. (N. S. Hibshman, AIEE, 33 W. 39 St., New York 18.)

22–24. American Council of Learned Societies, 39th annual, Bloomington, Ind. (ACLS, 2101 R St., NW, Washington 8.)

22–25. American Group Psychotherapy Assoc., 15th annual, New York. (M. Berger, 50 E. 72 St., New York 21.)

27–28. Scintillation Counter Symp., Washington, D.C. (G. A. Morton, Radio Corporation of America, Princeton, N.J.)

27–29. American Soc. of Heating and Air-Conditioning Engineers, Pittsburgh, Pa. (A. V. Hutchinson, ASHAE, 62 Worth St., New York 13.)

27–30. American Meteorological Soc., 163rd natl., New York. (K. C. Spengler, AMS, 3 Joy St., Boston 8, Mass.)

27–31. Institute of Aeronautical Sciences, 26th annual, New York, N.Y. (S. P. Johnston, IAS, 2 E. 64 St., New York 21.)

28–30. Aging, 4th Ciba Foundation Colloquium (by invitation), London, England. (G. E. W. Wolstenholme, 41 Portland Pl., London, W.1.)

28–30. American Mathematical Soc., 64th annual, Cincinnati, Ohio. (J. H. Curtiss, AMS, 190 Hope St., Providence 6, R.I.)

29–1. American Physical Soc., annual, New York, N.Y. (K. K. Darrow, Columbia Univ., New York 27).

30–31. College-Industry Conf., American Soc. for Engineering Education, 10th annual, Ann Arbor, Mich. (W. D. McIlvaine, College of Engineering, Ann Arbor.)

30–1. American Assoc. of Physics Teachers, New York. (F. Verbrugge, Univ. of Minnesota, Minneapolis.)

30–1. Western Soc. for Clinical Research, 11th annual, Carmel-by-the-Sea, Calif. (A. J. Seaman, Univ. of Oregon Medical School, Portland 1.)

31. Mathematical Assoc. of America, annual, Cincinnati, Ohio. (H. M. Gehman, Univ. of Buffalo, Buffalo 14, N.Y.)

31–1. Problems of Geriatrics, symp. (by invitation only), New York. (B. F. Chow, Johns Hopkins Univ., School of Hygiene and Public Health, 615 N. Wolfe St., Baltimore 5, Md.)

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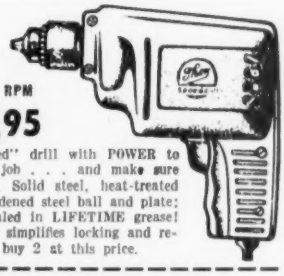

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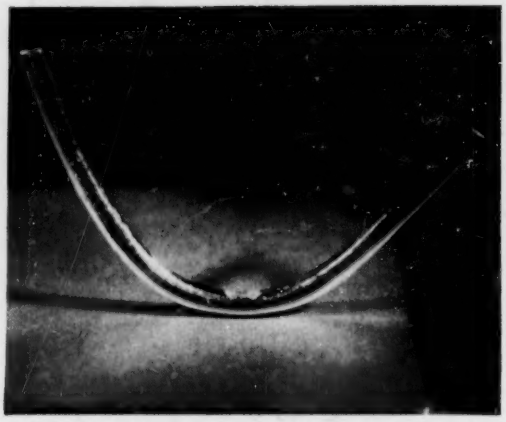

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new way to join metal to semiconductors

Thermo-compression bonding provides a new way to attach a wire to a semiconductor. It calls for heat and pressure – nothing else. The wire and the semiconductor are moderately heated, then pressed together under moderate pressure. The resulting bond is very strong—stronger actually than the wire. No chemical flux or molten metal is required.

Eliminating molten metal provides an enormous advantage in fixing electrical connections to transistors. That's because molten metal tends to spatter and spread uncontrollably over the surface of a semiconductor. And it may alloy with the semiconductor to alter its all-important crystalline structure and chemical purity. Thermo-compression bonding easily and quickly makes a strong permanent electrical connection without damaging the semiconductor. Furthermore, the lead may be attached to microscopic areas and precisely positioned, a most valuable aid in the construction of high-frequency transistors.

Thermo-compression bonding will speed the production of transistors . . . the transistors needed to fill all the new jobs Bell Laboratories finds for them in the quest for still better telephony.

At Bell Labs Howard Christensen and Orson Anderson discuss their discovery of new bonding principle with Peter Andreatch, Jr., who collaborated in the studies.

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